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CONTENTS

Library

AUTHOR INDEX

GENERAL INDEX

RADIO APPARATUS FOR AIRCRAFT AND GROUND STATIONS

By E. M. Kinney*

The use of various types of aircraft during the recent war has amply demonstrated the fact that they are indispensable to the fighting forces.

The Army scout and observation planes protected by the fighters, advance over enemy territory and collect valuable information relative to position and movement of troop units, location of supply depots, ammunition dumps, and other data practically impossible to secure before the advent of the airplane—while their value in directing artillery fire is of the utmost importance.

The Navy utilizes seaplanes and flying boats for submarine patrol, fire control, and general observation purposes, and at the present time has small land planes capable of taking flight from the turret of a battleship.

During the first few months of the war, communication between the commander and the planes in his squadron, and from ground stations to planes, was carried on by means of visual signaling and it was necessary for a plane, after obtaining some valuable information, to return to its base in order to convey this information to headquarters. All reports relating to effectiveness of artillery fire were also conveyed by means of visual signaling. This was, of course, a very inefficient manner of utilizing the valuable services of aircraft and steps were taken to provide the planes and ground stations with radiotelegraph sets which, at the time the United States entered the war, were used in a limited way by the French and English.

Some experimental radiotelephone apparatus had been constructed but it was crude and the results obtained were far from satisfactory.

Planes equipped with radiotelegraph sets require expert operators and although hundreds of amateurs offered their services

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it was foreseen that it would be necessary to give them considerable instruction in the operation of special devices and in addition it would be necessary to train thousands of others in the code and in radio theory in order to make them of value in this service. It was obvious that the radiotelephone, if a satisfactory one could be produced, would solve this difficulty as it would permit any pilot or observer, after a short period of instruction in the actual operation of the set, to receive directions and transmit information by telephone with ease and despatch. The telegraph, however, on account of its greater carrying distances for the same output, was recognized as a valuable adjunct which should not be neglected.

The problem was one of considerable magnitude. The apparatus must be extremely light and of small dimensions as the space available in a plane is limited and the aircraft manufacturer was naturally averse to having his plane loaded with extra weight, especially when this weight involved devices which were not vital to the successful functioning of the craft. The gas tanks, controls, instruments and other devices were located to the best advantage and it was necessary that the radio apparatus be designed to occupy as small an amount of the remaining space as possible.

The General Electric Company was one of the manufacturers called upon by the Government to assist in the solution of this problem and it is the purpose of this paper to outline in a general way some of the results of its activities. The development work for the Navy will be discussed first.

An aircraft radio set may be considered as consisting of three distinct parts, as follows:

1. The antenna system.
2. The transmitting and receiving devices.
3. The power supply.

The antenna system consists of a reel carrying a small phosphor-bronze cable, to the lower end of which is attached a lead weight shaped like a fish and weighing about two pounds. After the plane has ascended to a suitable height the operator can unreel this wire to the desired length—usually from two hundred to

three hundred feet, although five hundred or even six hundred feet can be used for special purposes if required. The wire must, of course, be reeled in before the plane makes a landing. When the plane is traveling at full speed this wire trails out at an angle of about thirty degrees from the horizontal for some three-fifths of its length, then gradually bends over in a curve until at a short distance from the lead fish the wire is hanging almost vertically. The counterpoise or ground side of the antenna circuit is formed by the flying wires, the braces, and all metal parts of the plane which are electrically joined so that good contact may be assured.

In order to effect radio communication while floating on the water, a flying boat can be equipped with a stationary antenna consisting of two or more wires running between the skid fins. The transmitting range with this small antenna is, of course, reduced, as will be shown later, but the fact that it is possible to carry on radio communication in case a plane is forced to make a landing is a valuable asset.

The larger flying boats carry a portable 30-foot mast and antenna which can be erected in a few minutes and with this antenna longer ranges can be attained than with the small antenna referred to above.

The General Electric Company was not called upon to conduct any development in connection with receiving devices, as the Navy engineers had designed a compact set which promised to fulfill their requirements and which has since proven to be satisfactory in every respect.

For transmitting, the pliotron, on account of its size, weight, and operating characteristics, was considered as the logical device for the generation of radio frequency currents applicable to either telegraphy or telephony.

The spark set is, of course, suitable for telegraphy *only*, while the arc, on account of its enormous weight and inability to oscillate at short wave lengths, was out of the question.

The pliotron (Fig. 1–3) consists of three elements—a tungsten filament, a tungsten plate, and a tungsten wire-mesh grid enclosed in a highly evacuated glass tube. The grid is interposed between the filament and the plate. When the filament is heated to incandescence by means of direct current of suitable voltage,

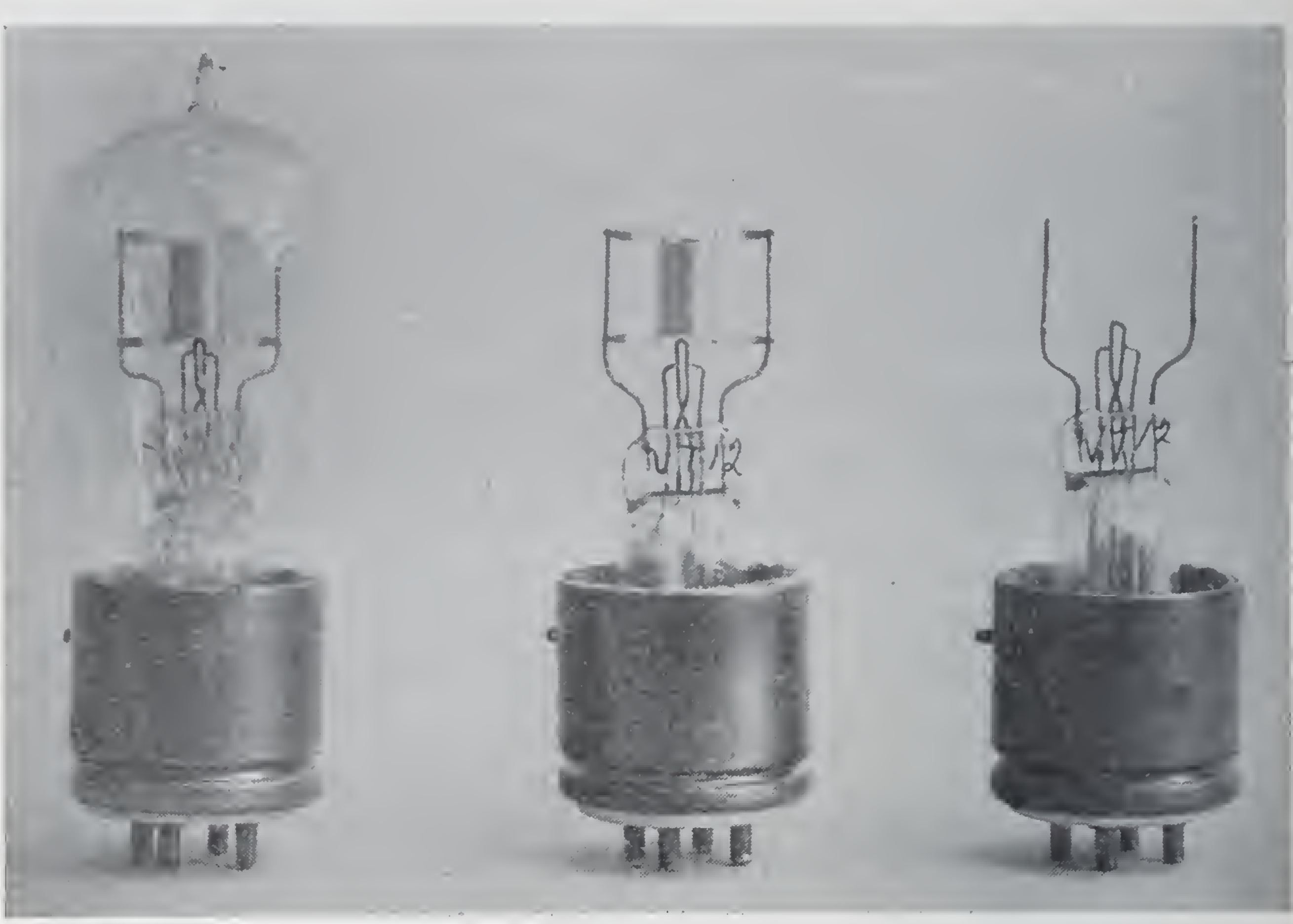

Fig. 1. Transmitting Pliotron, 5 Watts, Type VT-14.

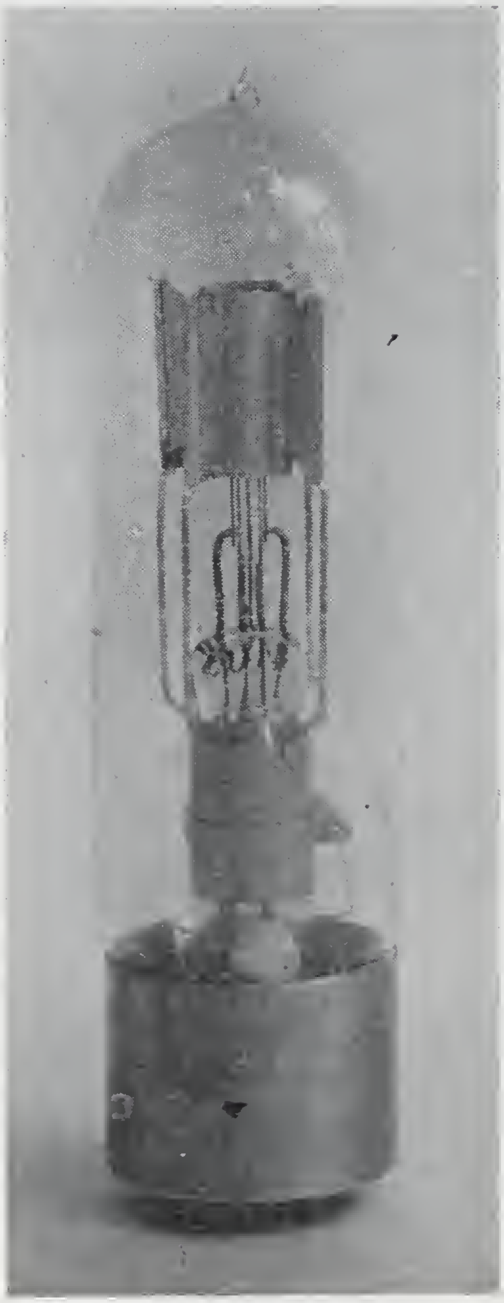

Fig. 2. Transmitting Pliotron, 50 Watts, Type VT-18.

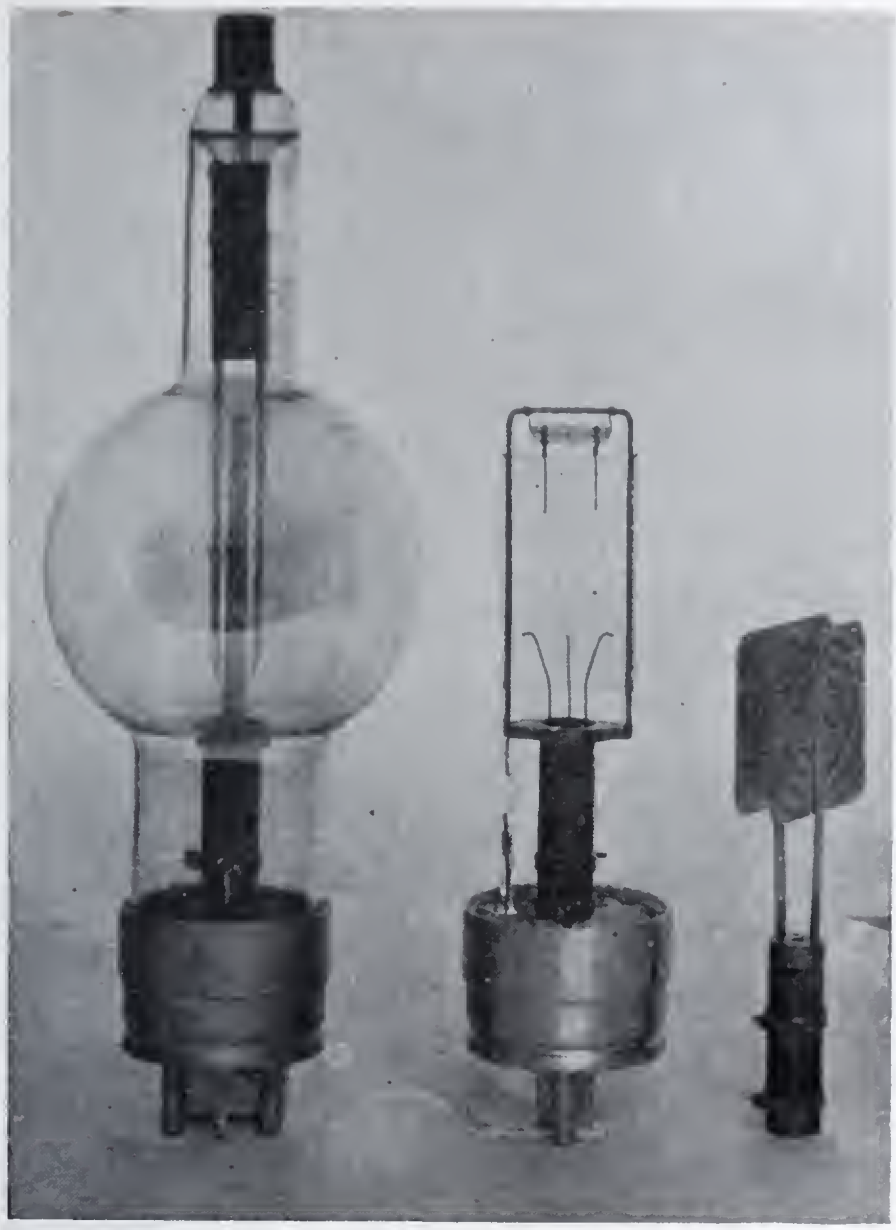

Fig. 3. Transmitting Pliotron, 250 Watts, Type P.

and a positive potential applied to the plate from a direct-current source, electrons are emitted from the hot filament and pass to the plate, the electronic flow being governed by the potential maintained on the grid. As the grid is made increasingly negative with respect to the filament, the electronic flow is correspondingly reduced until a point is reached where the flow entirely stops. Conversely, as the grid is made positive with respect to the filament the electronic flow is increased. Advantage is taken of this means of control to keep the tube operating at its most efficient point.

The characteristics of the pliotron are such that a slight change in potential impressed on the grid circuit causes a much greater relative change of electron current between the filament and the plate. The advantage of this feature will be shown later.

By means of suitable inductances in series with the plate and grid and mutual coupling of these, the tubes may be made to oscillate and they then become generators of radio frequency currents at practically any frequency desired. This renders the pliotron particularly valuable for telephony where a continuous wave is utilized as the carrier wave for the modulated voice frequency currents.

The fundamental circuit used with minor variations in all transmitting sets furnished by the Company consists of an inductance coil in series with the antenna, inductively coupled to which are the pliotron plate and grid inductances.

The general theory of operation is as follows: When the filament is lighted and a positive potential applied to the pliotron plate a slight transfer of energy takes place between the plate and antenna systems and feeble natural oscillations are set up in the antenna circuit. Due to the inductive relation between the grid and antenna coils these feeble oscillations are impressed on the grid of the oscillator tube. This gives rise to similar but amplified oscillations in the high-voltage plate circuit, which, through its inductive relation to the antenna coil, reinforces the oscillating current in the antenna circuit. This action is repeated with the antenna current constantly increasing until limited by the tube and antenna characteristics. A grid condenser and resistance leak are supplied to keep the grid at proper negative potential.

The constants of the plate and grid coils depend upon the constants of the tube and antenna. The antenna coil depends upon the antenna constants and the wave length requirements. For telegraphy, the key may be inserted either in series with the grid leak or in the grid circuit—in the latter case bridged by a condenser. When the key is opened the grid becomes negatively charged and oscillations instantly cease. When the key is closed the pliotron again starts oscillating.

In order to reproduce speech it is necessary to modulate or vary the oscillating current in the antenna (which acts as the carrying wave) to correspond to the frequency and relative amplitude of the current in the microphone circuit as affected by the voice. This is accomplished in the following manner: A microphone transformer—with its primary in series with a six- or

seven-volt direct-current source and a microphone transmitter—supplies from its secondary a small current at voice frequency which is led to the grid of another pliotron called the modulator. The resulting amplified energy output from the plate of this modulator is introduced into the plate circuit of the oscillator and passed through an iron core reactance. The voltage built up across this reactance, due to the amplified speech currents, combines with the high voltage normally impressed upon the plate of the oscillator, thereby modulating the radio frequency output.

For modulated or interrupted telegraphy, a buzzer and key are used in the primary of the microphone transformer instead of the microphone transmitter. It is, of course, essential that the amplifier or modulator tube be operated on the proper portion of its characteristic curve, which is accomplished by using a negative grid potential supplied by dry-cell batteries or by taking a drop in potential from the grid leak.

The first small transmitting set developed (Fig. 4–5) uses three of the VT-14, five-watt pliotrons—one being the oscillator and two being modulators. Tests with the tubes then in use demonstrated the fact that this combination gave much better modulation than with one modulator and two oscillators, or one of each. The cabinet is 11 inches wide, 9¾ inches high and 9¾ inches deep, while the weight is 13 pounds. A small 50-watt dynamotor, shown in Fig. 4, weighing 10½ pounds and taking its energy from a 12-volt storage battery, supplies the necessary direct-current at 350 volts for the plates of the pliotrons. This dynamotor is connected to the set and battery by flexible leads with polarized plugs. The weight of the complete outfit including transmitting and receiving sets, battery, dynamotor and all accessories is approximately 122 pounds.

The panel forming the front of the cabinet carries on its reverse face the pliotrons, radio coils, transformers and other necessary devices, and is arranged so as to swing out from the containing cabinet to permit of tube renewals or inspection. Slip hinges allow the entire panel to be quickly removed from the cabinet when desired.

The radiation and filament ammeters are shown, respectively, at the left and right upper corners of the panel, while the antenna

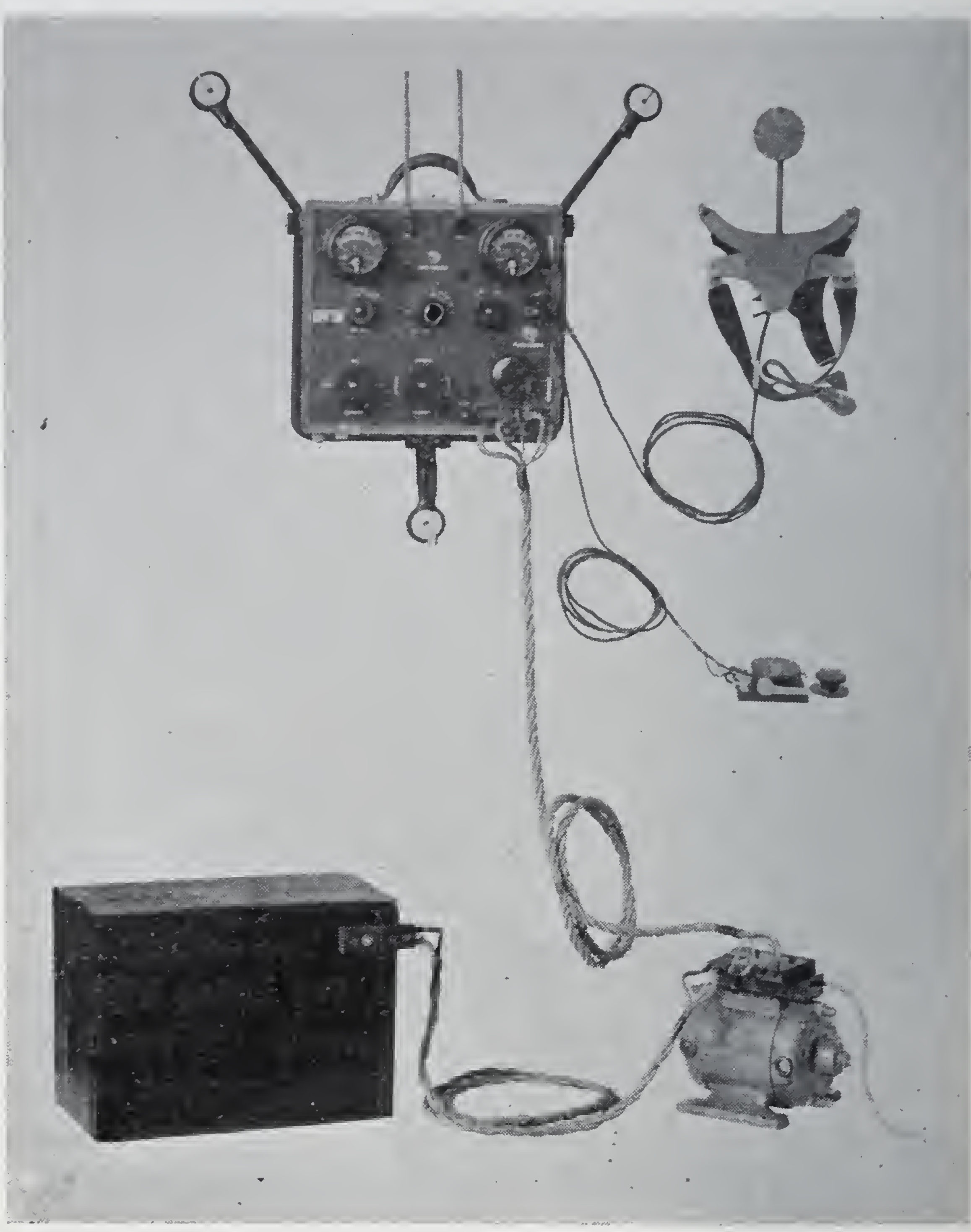

Fig. 4. Navy Aircraft Radio Transmitting Set, Type CG-1104.

and receiving posts are shown at the top center. Directly between the meters is the wave indicating lamp which shows when the set is in resonance for wave lengths of 335–375 and 425 meters for which the coil system was designed. Selection of wave lengths is secured by means of three taps brought out from the antenna coil to a switch on the rear of the panel, and intermediate adjustment in inductance to compensate for varying antenna constants on different planes is secured by use of the variometer in the center of the panel directly below the wave indicator lamp.

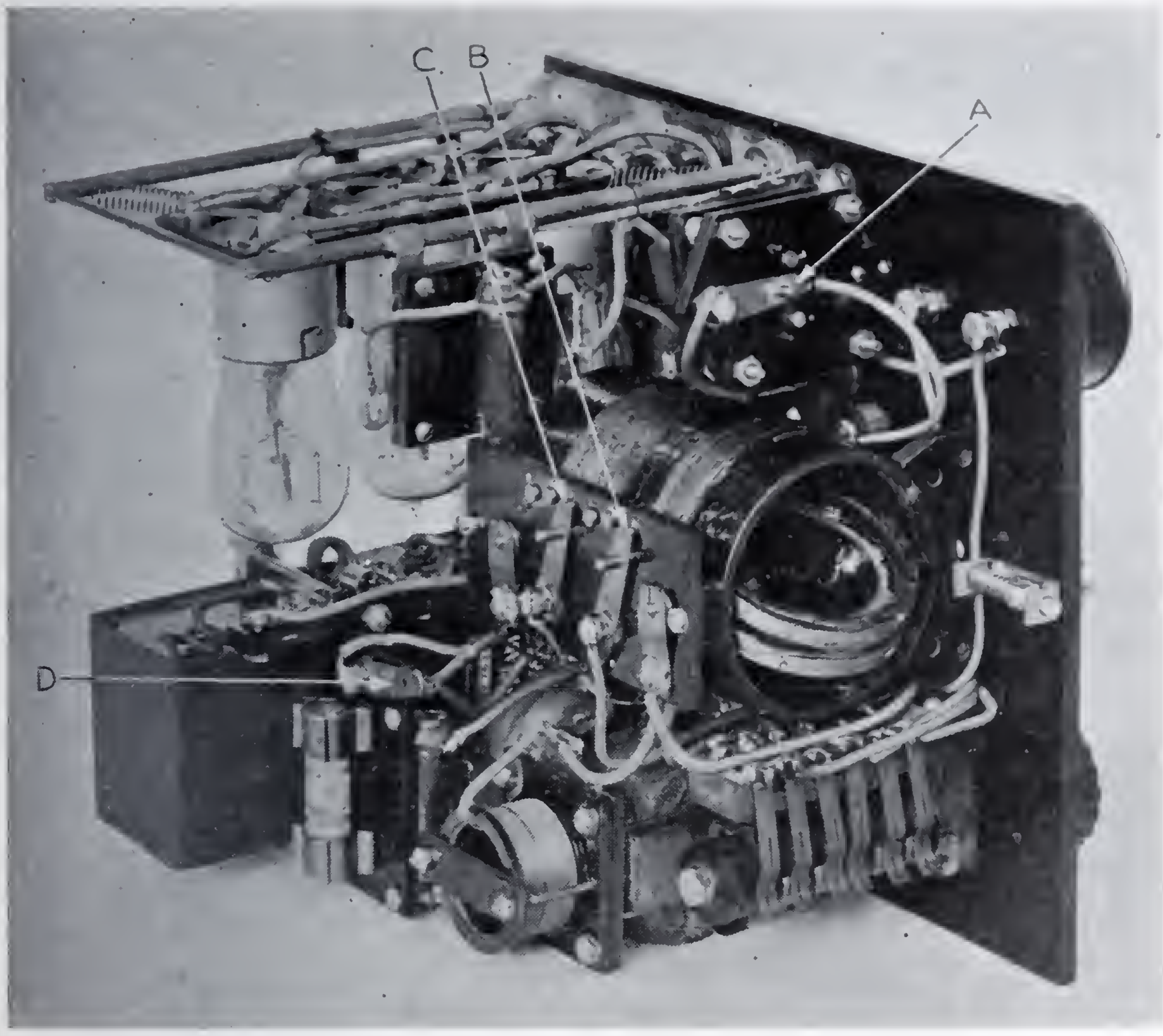

Fig. 5. Navy Aircraft Radio Transmitting Set, Type CG-1104.

To the left of the variometer is a knob for adjusting the degree of grid coupling for maximum output, and to the right of the center is the test switch. This switch enables the operator to put the set in operation on a phantom antenna preliminary to flight, and thus determine whether the apparatus is functioning properly. This phantom antenna consists of a capacity which absorbs approximately the same current as the antenna. This feature is a great time saver and is often the means of locating antenna trouble, such as a broken or grounded antenna wire, by differentiating between trouble in the set and trouble in the radiating system. The test switch is held in normal operating position by a spring so that it is impossible to leave the phantom in circuit after the knob is released.

In the left lower corner is the transfer switch which, in the central position (for receiving) connects the antenna through the

set to the receiver. Connections are made for buzzer modulated telegraphy when the switch is turned to the left; for telephony, when turned to the right. When thrown to either of the latter positions the dynamotor for supplying direct current to the pliotron plate circuits is automatically started.

At the bottom center of the panel is the rheostat handle for controlling current to the pliotron filaments. The buzzer is shown in the lower right corner while directly below are the jacks for the dynamotor plug. Jacks for microphone and key are shown on the right of the panel below the filament ammeter. Directly below these jacks is a lamp in the plate circuit of the oscillator tube. This lamp is a very effective indicator of the modulation, the brilliancy rising and falling as the microphone is spoken into or the key pressed in dots and dashes.

In an airplane, vibration is excessive and in order to protect the pliotrons from its effect they are mounted on the panel by means of a spring supported carrier. This method of support has proven very effective. To protect the entire cabinet from the effects of vibration it is supported in the airplane by means of three-point flexible cord suspension, as shown in Fig. 4.

This set has on several occasions been used in talking for a distance of 75 to 80 miles from a plane to a ground station, and in the absence of strong local interference every word was understandable. The receiver used was the standard Navy aircraft type with two stages of audio amplification. Antenna current was from 0.6 to 0.7 amperes.

The official ranges covered by this set as given by the Navy are as follows:

	Trailing antenna	Skid-fin antenna Plane on water
Continuous wave telegraphy....	100 miles	50 miles
Telephone	60 miles	20 miles
Buzzer modulated telegraphy....	75 miles	30 miles

It should be understood that these distances, and those given later as referring to other types of sets, are not the possible max-

imum over which the set is capable of working, but represent ranges over which the regular operators have, so far, been able to maintain satisfactory communication.

During the recent fleet maneuvers at Guantanamo Bay, one of the small ship airplanes was equipped with one of these sets and used for spotting big-gun fire. According to the official reports, the accuracy was improved 200 per cent. and the credit was rightfully assigned to the use of the radio equipment in connection with the plane.

The transmission of engine noise through the microphone was at first a serious problem but this has been practically overcome by using a microphone with a diaphragm of which the natural period differs considerably from that of the vibrations due to the engine. Another type employs a diaphragm open both front and back so that the effect of engine vibration is neutralized. The operator's lips are pressed fairly close to the diaphragm when telephoning, and voice vibrations, on one side only, produce the desired results.

The smallest radiotelephone and radiotelegraph transmitting set developed for the Navy is shown in Fig. 6 and is contained in a cabinet 8¼ inches wide, 8¼ inches high and 6½ inches deep, weighing 8½ pounds. This set utilizes the same 50-watt, 350-volt dynamoter described above. Two of the VT-14, 5-watt pliotrons are used—one as an oscillator and one as a modulator. Wave length ranges are 335–375 and 425 meters and the set is arranged for telephony, buzzer modulated, and continuous wave telegraphy. The weight of the complete radio transmitting and receiving equipment and accessories is 117 pounds.

This set has duplicated the performance of the set first described, occupies a very small space and can be used on extremely small planes. Both this and the preceding set are especially adapted for use on dirigibles commonly known as "blimps."

A larger set (Fig. 7), employing two 250-watt pliotrons, is used in connection with the large flying boats. One of these tubes is used as an oscillator and the other as a modulator. The cabinet

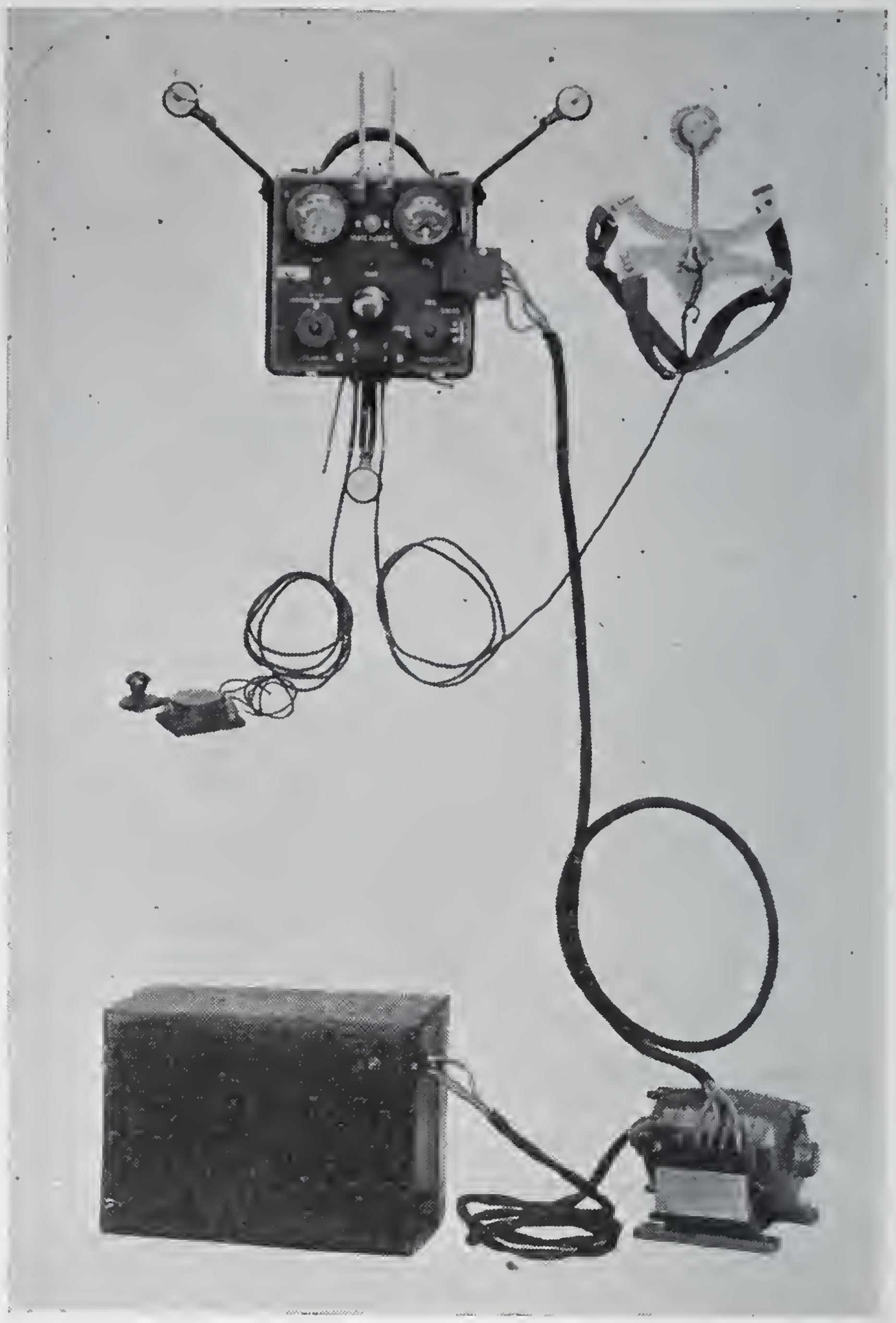

Fig. 6. Navy Aircraft Radio Transmitting Set, Type CG-1104A.

measures 20 inches wide, 19 inches high and 11 inches deep, and weighs 40 pounds, and 1500-volt direct current is supplied by a 350-watt dynamotor which derives its energy from a 24-volt storage battery. This dynamotor weighs 28 pounds. The set is designed for telephony, buzzer modulated, and continuous wave telegraphy on 600- and 1600-meter wave lengths, putting into the antenna five amperes on 600 meters and 3¾ amperes on 1600 meters for continuous wave telephony using one pliotron as an oscillator. The complete transmitting and receiving equipment weighs 229 pounds.

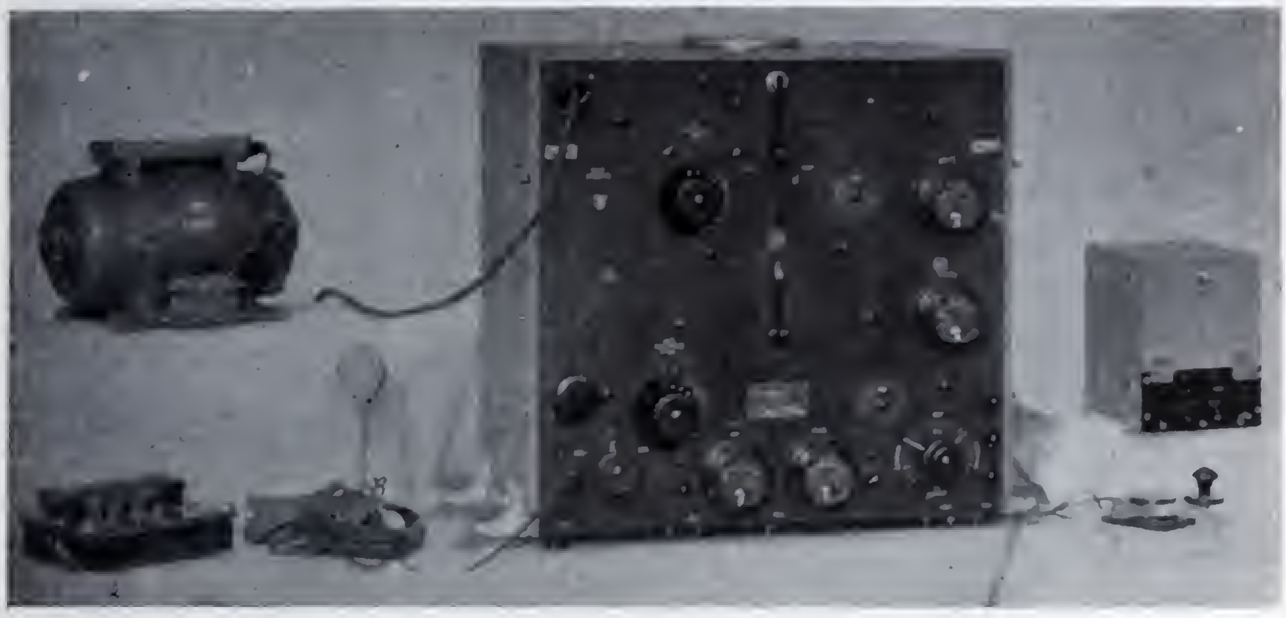

Fig. 7. Flying Boat Radio Transmitter, Type CG-1130.

Navy reports indicate the following ranges for this set:

	Trailing antenna	Skid-fin antenna Plane on water
Wave length, 600 meters.		
Continuous wave telegraphy....	250 miles	175 miles
Telephone	150 miles	75 miles
Buzzer modulated telegraphy....	190 miles	90 miles
Wave length, 1600 meters.		
Continuous wave telegraphy....	160 miles	135 miles
Telephone	125 miles	100 miles
Buzzer modulated telegraphy....	140 miles	115 miles

In order that the voltage applied to the modulator grid shall be of greater magnitude than is given by the microphone transformer alone, the General Electric Company supplies a modulation amplifier (Fig. 8) which utilizes a five-watt tube. The grid of this tube is connected to the microphone transformer while the amplified voltage from the plate circuit is impressed upon the grid of the modulator tube. This amplifier is built as a unit and can be applied to any set as desired.

A light set (Fig. 9–10) for use on sea-planes, utilizes two VT-18, 50-watt pliotrons in the same manner described above. The cabinet is 14½ inches wide, 14½ inches high and 8 inches deep weighing 18½ pounds. Wave length range is 425 and 600 meters. An extra radio coil for 850 meters is supplied and can easily be substituted for the 425-meter coil when desired. Out-

Fig. 8. Modulation Amplifier.

put in the antenna is approximately 2 amperes on 600 meters and 1½ amperes on 850 meters. A 150-watt dynamotor, deriving its energy from a 24-volt storage battery, supplies direct current at 750 volts for the pliotron plates. This dynamotor weighs approximately 17 pounds. The complete transmitting and receiving equipment weighs 180 pounds.

Navy reports indicate the following ranges for this set:

	Trailing antenna	Skid-fin antenna Plane on water
Wave length, 425 or 600 meters.		
Continuous wave telegraphy....	175 miles	90 miles
Telephone	85 miles	45 miles
Buzzer modulated telegraphy....	100 miles	60 miles
Wave length, 850 meters.		
Continuous wave telegraphy....	125 miles	65 miles
Telephone	60 miles	30 miles
Buzzer modulated telegraphy....	80 miles	45 miles

Fig. 9. Navy Aircraft Radio Transmitter, Type CG-1410.

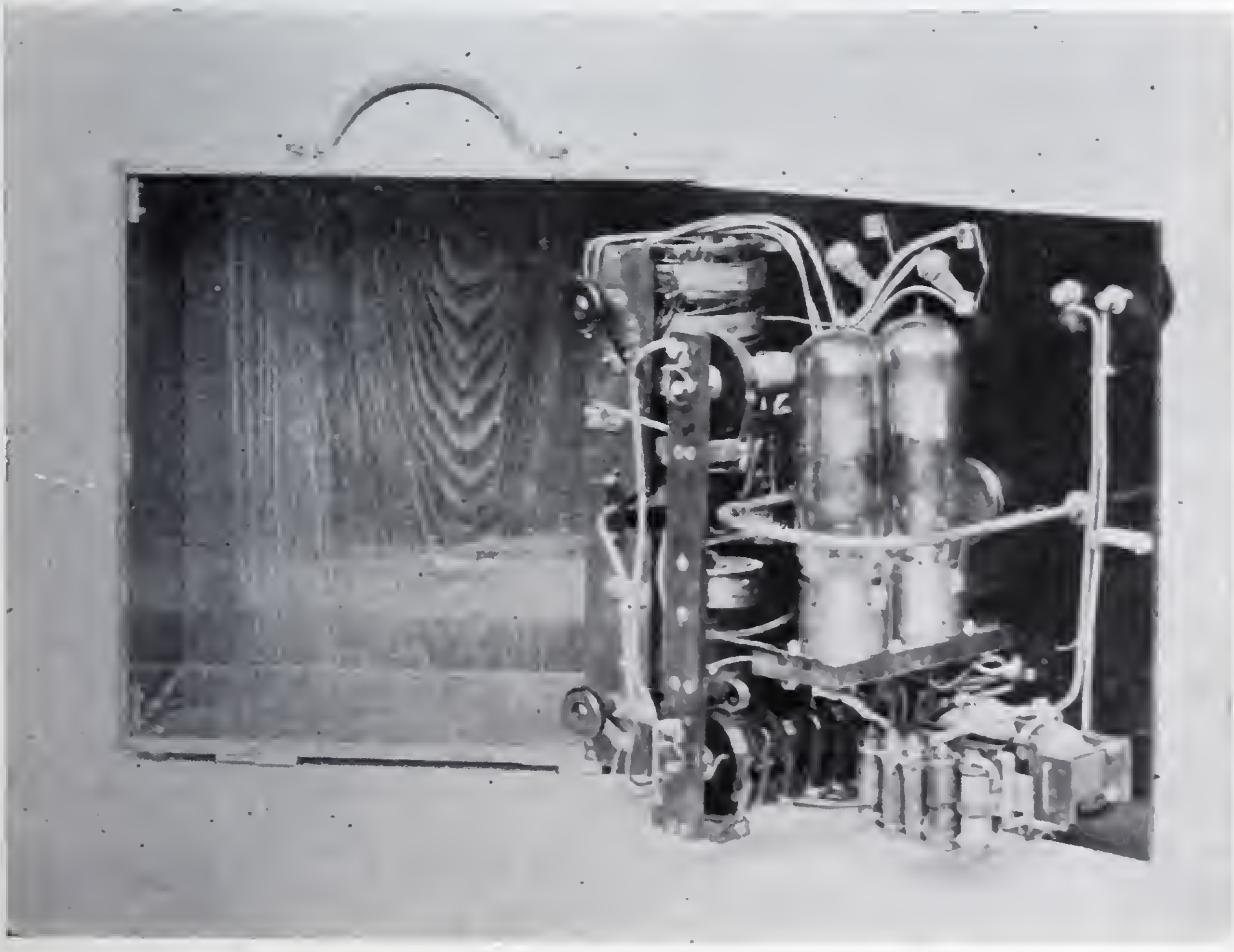

Fig. 10. Medium Power Pliotron Transmitting Set, Rear View.

Another set has been developed using two similar tubes working on a wave of 375 meters only. The output and range of this set are the same as for the preceding set.

The largest radiotelephone and radiotelegraph set built for use on a flying boat, utilizes six VT-18, 50-watt pliotrons. This set operates on wave lengths of 600 and 800 meters and will put about eight amperes of current into the ordinary trailing antenna. It is 20 inches high, 20 inches wide, and 18¼ inches deep and weighs 27 pounds. The complete transmitting and receiving set weighs 178 pounds.

A combined radiotelephone transmitter and receiver has been developed for use on a single-seater airplane. This set utilizes two VT-14, five-watt pliotrons for the transmitter, and three VT-11 pliotrons for the receiver. The receiver consists of a detector tube and two stages of amplification. Only one wave length of 238 meters is employed in this set. The panel contains a transfer switch to change from transmitting to receiving, a lamp used as a modulation indicator, and jacks for the microphone and receiver. The knob on the left side of the panel is for grid adjustment. Receiver tuning is obtained by means of a variable inductance controlled by a knob on the left side of the panel. Power is supplied by a wind driven generator. The set is 14¼ inches wide, 5¾ inches high, and 7¼ inches deep and weighs 12 pounds. The complete set weighs 41 pounds.

For communicating over long distances from base stations to planes, the General Electric Company manufactures a telephone and telegraph transmitting set (Fig. 11) utilizing six 250-watt pliotrons, three of which are used as oscillators, three as modulators and a VT-14, five-watt pliotron as an amplifier. This amplifier tube is inserted between the microphone transformer and the grids of the three modulator tubes in order that the voltage applied thereto shall be of greater magnitude than is given by the transformer alone. For continuous wave telegraphy, three tubes are used as oscillators. This set is approximately 3½ feet high, 3 feet wide, and 2½ feet deep and weighs, with tubes, about 300 pounds. A two-kilowatt, motor-generator set supplies 2000-volt direct current for the pliotron plates and 90-volt alternating current which is transformed to 50 volts

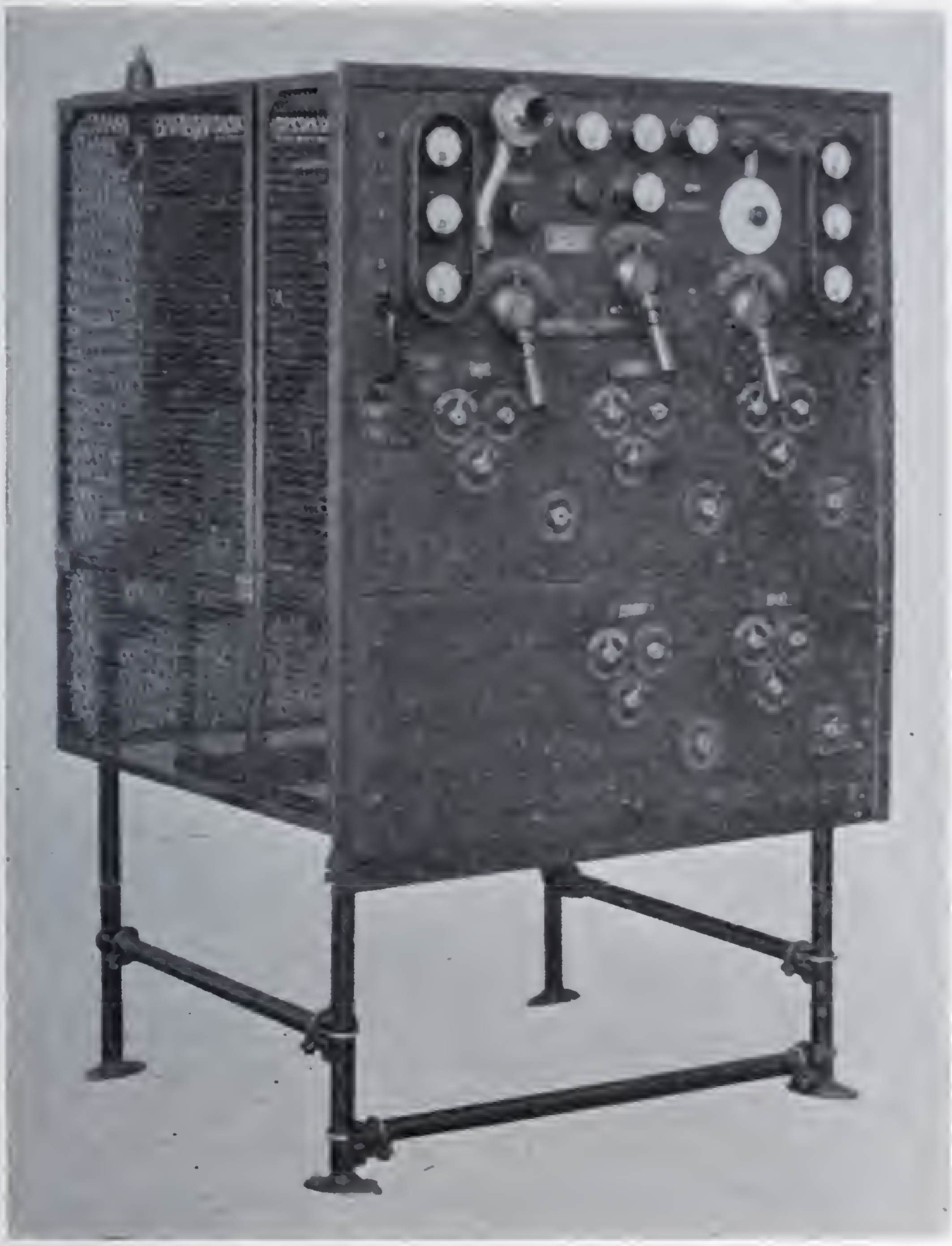

Fig. 11. Front View of 3.5-Kilowatt Navy Transmitter Set, for Radiotelegraphy and Radiotelephony.

for the filaments. Transmitting sets are designed for operation from either alternating-current or direct-current source of supply, and five wave lengths within a range of 600 to 2200 meters. Changes from one wave length to another are made by means of a switch operated from the front of the panel. The transfer switch, when thrown to the transmitting position, automatically starts the motor-generator set and closes the filament, grid potential, and microphone battery circuits. When this switch is thrown to the receiving position, the motor-generator is stopped by means of dynamic braking. This set, using three tubes as

oscillators, will deliver 11 to 12 amperes into an eight-ohm antenna on a wave length of 1600 meters.

Telephone conversation from one of these sets installed at Washington has been clearly heard in Maine—700 miles; in Charleston, S. C.—500 miles; and in Schenectady, N. Y.—350 miles distant. Complete messages by telephone have been copied on an airplane, with two Liberty motors running, at a distance of 200 miles and it is believed satisfactory telephone communication can be established at greater distances, as will undoubtedly be demonstrated by further tests. It is interesting to note that telephone signals from this set have been received clearly and with considerable intensity by a receiver located in an airplane resting on the ground 135 miles distant, the receiving antenna consisting of a wire 75 feet long leading from the plane to a post five feet high. Loud and clear signals were also received using only a coil of wire of a few turns located inside the body of the airplane.

There has been developed for the United States Signal Corps, for communication between planes for squadron control, a combined radiotelephone transmitting and receiving set for wave lengths of 85–100, and 115 meters. The antenna with which these sets work consists of two wires, each 50 feet long, one trailing from each outboard strut. The receiving and transmitting sets consist of separate units to be mounted on the floor of the airplane and operated by the pilot by remote control. This set includes the interphone feature enabling the pilot and observer to maintain telephone communication with each other, as desired. The transmitting set (Fig. 12) is about 8 inches wide, 7 inches high and 7½ inches deep, weighing 7¾ pounds. Two VT-14, five-watt pliotrons are used, one as an oscillator and the other as a modulator. The output into the antenna is about 0.8 amperes.

The receiving set has the same overall dimensions as the transmitting set and employs three VT-11 pliotrons, one used as a detector and two as amplifiers. This set weighs 7½ pounds. The receiving and transmitting sets are each inclosed in a moisture-proof box.

The pilot's control cabinet is 6 inches wide, 7½ inches high, and 4 inches deep, and contains an antenna tuning condenser

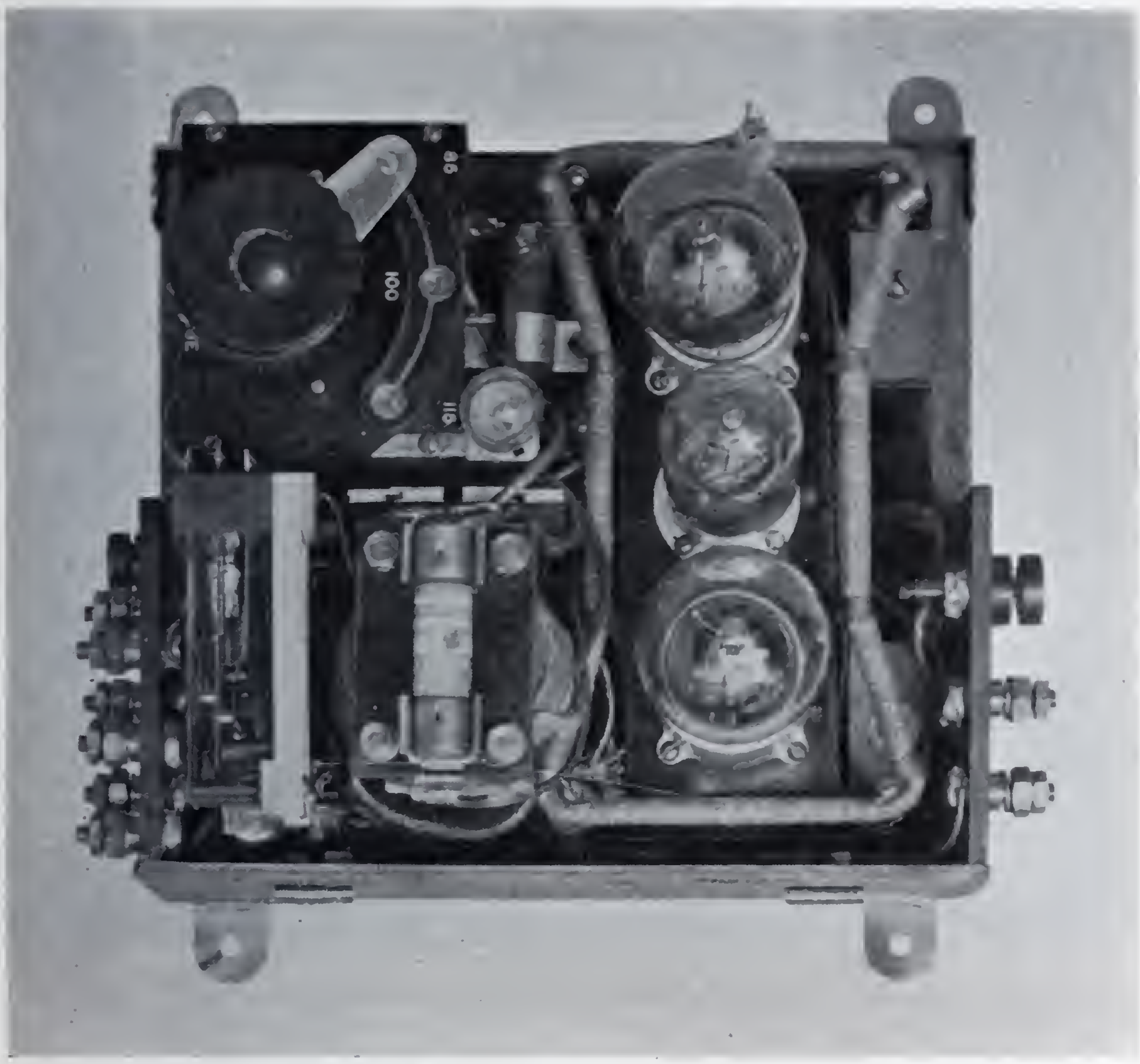

Fig. 12. Short-Wave Radiotelephone Set Transmitter.

and an induction coil for interphone and side tone circuits. The weight is 3¾ pounds.

The observer's interphone box is 3 inches wide, 4¾ inches high, and 3 inches deep and weighs 1 pound. This contains the push-button.

Plate current of 350 volts and filament current of 27½ volts are supplied by a wind-driven generator mounted on the wing of the plane and regulated by means of a self deflecting fan or pliotron control.

It should be understood that, on account of the excessive noise of the engine, the transmission range between planes is greatly reduced as compared with distances secured from an airplane to ground stations. A set which will satisfactorily work 60

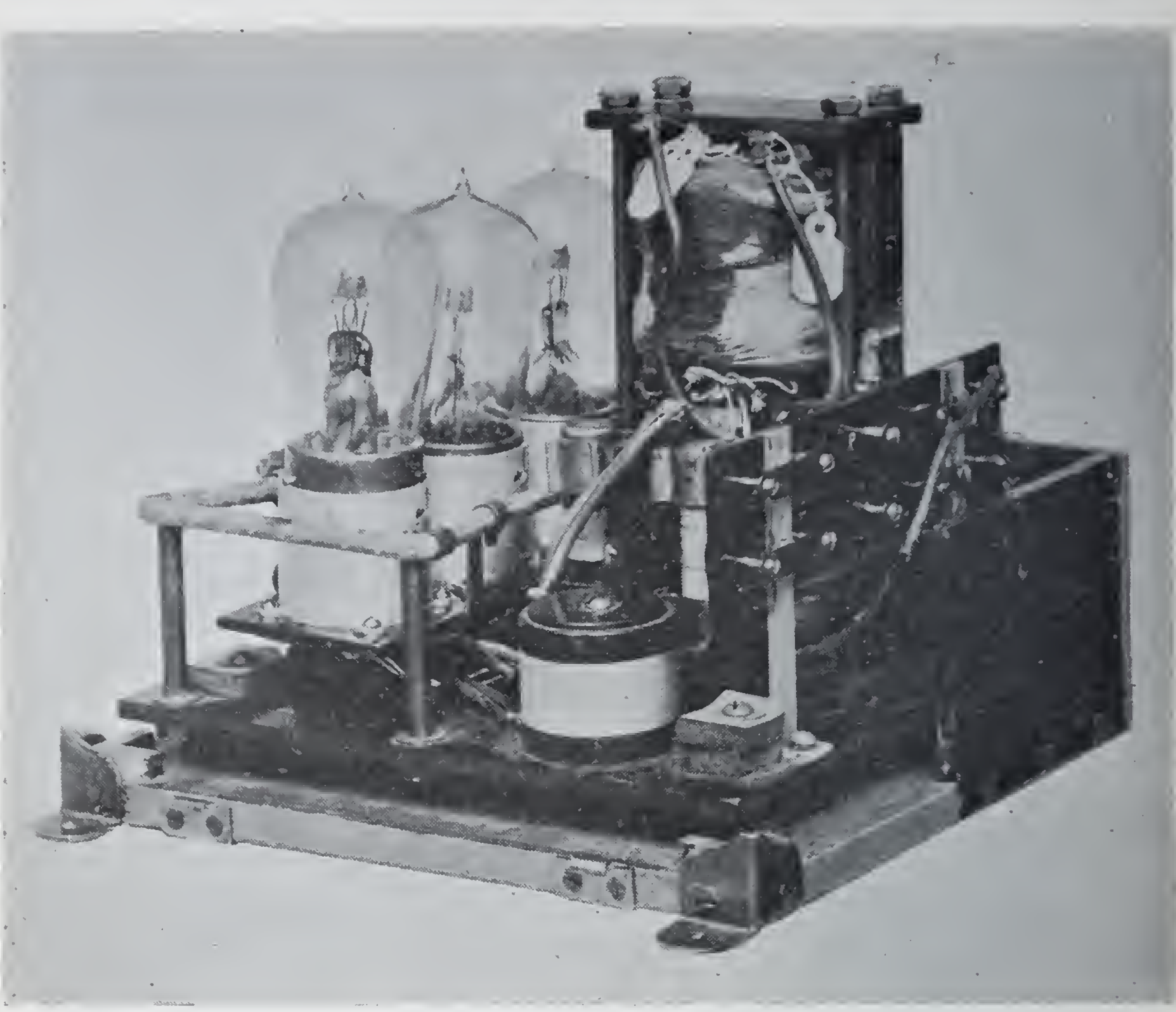

Fig. 13. Short-Wave Radiotelephone Set Receiver.

miles from an airplane to the ground will work only from 10 to 12 miles between planes.

A continuous wave telegraph set, similar to the six-pliotron set previously described, has been supplied to the United States Signal Corps. This set was used in a tractor, forming a portable base station capable of communicating with airplanes or widely scattered troop units. The tractor carries a jointed wooden mast capable of a maximum height of 80 feet with which is used an umbrella antenna consisting of 12 wires and 12 counterpoise wires which are laid on the ground directly under the antenna. This set was designed for continuous wave telegraphy only, and, therefore, all six tubes are used as oscillators. Wave length range is 600-900, and 1200 meters. Flexible spring mounting is provided for the pliotrons in order to obviate damage from shocks and vibration while the tractor is in motion. Generators suitable for furnishing current to filaments and plates at required voltage

are driven by means of the tractor's gasoline motor through suitable gear shifts.

Tests conducted by the United States Signal Corps, using a mast 64 feet high, showed a range of 1300 miles with an antenna input of 15 amperes.

The United States Post Office Department has outlined an extensive program of air mail service, and ground stations will be provided for guiding airplanes to their destinations and communicating with the planes which will be equipped with direction finding apparatus and radiotelephone sets.

It is understood that the airplane has been used very successfully in the detection and location of forest fires and the importance of the radiotelephone in this connection is obvious.

In order to utilize the services of all types of aircraft to the best advantage it is essential that they be equipped with radio apparatus and we may confidently look forward to developments of considerable magnitude in the near future.

DISCUSSION

Mr. S. M. Kintner:* Mr. Kinney has handled very cleverly a subject that is difficult to popularize. His frequent reference to his experiences in flying, during the development of the aircraft radio apparatus, was no doubt greatly enjoyed by those in the audience not up on the radio art. The rest of us enjoyed it all. I do not think, however, that Mr. Kinney's remarks will tend to popularize flying.

It is noted that the greater part of the paper is devoted to a description of apparatus developed for the United States Navy, and this prompts the question of what was done for the Army.

Another question I should like to ask Mr. Kinney is whether pliotrons larger in size than 250 watts have been commercially developed to a stage of perfection?

As a matter of interest in connection with the subject of aircraft radio equipment I will state, briefly, several facts in my possession regarding the radio equipment used by the United States Navy in the transatlantic flight. This equipment was supplied by our Company—the International Radio Telegraph Company—and as a result of that fact I had excellent opportunities to learn of what was done.

The undertaking was in charge of officers who were primarily fliers and they were more interested in having an ample supply of gasoline and food than they were in having radio equipment. Some of them opposed taking radio direction finders on account of their lack of faith in them, and also on account of their feeling of security with ships scattered along their course only 50 miles apart.

As a compromise, the permissible radio equipment was limited to 165 pounds. By careful design and selection it was found possible to stay within these limits and have a ½-kilowatt, high-frequency spark transmitter, driven by an air propeller, designed for 300-mile operation; a small tube set operated from a storage

*Vice-President and General Manager, International Radio Telegraph Co., Pittsburgh.

battery, to be used when on the water; the radio direction finders, mounted in the fuselage; and a receiving set.

All of this equipment worked in a satisfactory manner with the exception of the direction finders. These were found to be subject to serious interference from the ignition system, which was changed the day before the flight. This interference was so serious that it was impossible to read signals sent for the use of the finders, when the sending station was more than four or five miles away.

Ensign Rodd, on the NC-4—the one airplane that was successful in completing the flight—discovered that, without impairing the ignition system, he could eliminate this interference by disconnecting certain of the troublesome wires during the time he desired to use the radio direction finder.

By many of the Navy officers the success of this airplane is attributed to the use of direction finders which made it possible to keep directly on the course, while the other two boats, not using the direction finders, lost their way in the fog and wandered many miles from their course. The Navy considers the demonstration of the successful use of the direction finders to be the most valuable feature of the flight.

The ½-kilowatt spark set did wonderful work. One message was copied at Bar Harbor, Me., when the NC-4, which sent it, was over 1400 miles away.

As the greater part of Mr. Kinney's paper is devoted to the radiotelephone, I think it proper to say that the inventor of this remarkable mechanism is a former Secretary of the Society—Prof. R. A. Fessenden.

Mr. E. M. Kinney: Our initial development was carried on for the Navy, primarily because it needed sets of greater power than required by the Army, and we knew that our large tubes were particularly adapted to that class of apparatus. Later, we developed for the Navy small tube sets which were found to be more efficient than similar sets of other manufacture with which they were experimenting.

We made several developments in small tube sets for the Army but continual changing, and incorporation of improvements

suggested by the Signal Corps, resulted in very little of this apparatus getting beyond the experimental stage. The set we finally developed was installed and ready for test the day the armistice was signed, at which time all development work was stopped. The two-kilowatt tractor set was also developed for the Army and we are now building several of these sets for its use.

In regard to the pliotron, the 250 watt is the largest tube used commercially at the present time. The six tube sets which we are building for both the Army and the Navy utilize these tubes.

In this connection, it might be interesting to know that a few weeks ago the Navy conducted a series of tests in Washington to determine the relative distances which could be obtained with the spark, arc, and tube sets. These tests ran for six days and six nights, sending for five minutes with the spark set, putting eight amperes into the antenna; the next for five minutes with the arc set, putting the same current into the antenna; and the next five minutes with the tube set putting in the same current. These tests were very carefully recorded and compared and it was found that on the basis of 1000 audibility for the tube set, the arc set had an audibility of 800, and the spark set an audibility of 50 to 100. That shows about the relative values of continuous wave transmission as compared with the arc set and the spark set.

I have had many opportunities to observe the International aircraft spark set in use and can speak very highly with regard to its performance.

Mr. J. B. Mandeville:* I would like to ask if there are any records of transmission on underground antenna. Much has been done in receiving, but has anything been accomplished in transmitting?

Mr. E. M. Kinney: Some work has been done in connection with transmitting on underground antenna but the resistance and absorption are very high, necessitating the use of high power for comparatively short distances. Personally, I do not anticipate an extensive use of this method of transmission in the near future.

*Chief Engineer, T. W. Phillips Gas & Oil Co., Butler, Pa.

SUPERHEATERS AND THE UTILIZATION OF SUPERHEATED STEAM

By D. D. Pendleton* and C. A. Brandt†

OUTLINE

INTRODUCTION

It is a great pleasure to have the opportunity of submitting a few facts and observations upon the subject of Superheaters and the Utilization of Superheated Steam. It is a topic of great importance at the present time. No doubt you are all familiar with this subject, and it is not the purpose of this paper to enter into theoretical discussion of the thermodynamics or the early history but merely to point out what can be accomplished, for the purpose of bringing about a discussion of the subject from a practical standpoint.

Fifty years ago, in 1869, there were in the United States about 31,520 steam horse-power in operation for each million population. In 1915, the latest statistics available, there were 294,220 horse-power per million population—an amount which represents an increase of over 800 per cent. in about 45 years.

It is true that great improvements have been made in steam engineering practice, and the steam prime mover of to-day, as represented by the large, modern steam-turbine, is very efficient. The power generated by this type of prime mover, however, is a very small proportion of the total power developed, as it is the small isolated plants that generate the greater part of the power. Out of about 30,000,000 steam horse-power used in industries,

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only 5,000,000 are in central stations having efficient equipment. Small plants, inherently less economical, are in greatest need of improvements.

In 1912, there were produced in the United States about 450,000,000 tons of bituminous coal and 75,000,000 tons of anthracite, or a total of 525,000,000 tons; in 1917, about 532,000,000 tons of bituminous coal and 89,000,000 tons of anthracite, or about 621,000,000 tons. This is an increase of 96,000,000 tons, or about 20 per cent. in five years.

The tremendous increase in the consumption of fuel, its world-wide scarcity, and the great increase in its cost, make it the duty of this generation to conserve and preserve this most essential material. As the largest part of our fuel is utilized for the production of power, every effort known to engineering and science should be made to convert into useful work the greatest possible portion of the energy in the coal. The purpose of superheating is to *save fuel* by increasing the efficiency of the steam prime mover.

Per dollar invested, the application of superheated steam will produce a greater and more positive increase in the efficiency of steam power-plants than any other single factor used in steam engineering to-day. In certain branches of steam engineering, the practice of superheating has increased in a remarkable manner, while in others the progress has been very slow.

In railway service, twenty years ago, very few of the world's locomotives were equipped with superheaters, and as recently as ten years ago there were only about five hundred locomotives out of the 65,000 in this country so equipped. Nothing has been more remarkable in the history of the locomotive than the rapid increase in the use of highly superheated steam. In this service 250 degrees, or more, of superheat are employed. As an indication of the progress made, it can be said that nearly all locomotives built in the last eight years have been equipped with superheaters, and a total of about 37,000 locomotives so equipped are now in operation in this country. Similar progress has been made in other countries, and the utilization of high superheat is general practice in locomotives not only in Europe but also on other continents.

High-degree superheat for marine service has been widely adopted in all foreign countries, and this has been particularly true during the past year. The application of superheaters in marine service in our own country, however, has been much slower although an awakening of interest is being manifested by our marine engineers. This has been brought about by a realization of the fact that if we are to operate ships in competition with other nations we must equal or excel others in the effective use of fuel.

The fuel cost in marine service is about 25 per cent. of the total cost of ship operation and an economy of 12 to 15 per cent. in this item may mean the difference between profit and loss. If there is any place where the utilization of equipment producing highest economy in fuel is in order, it certainly is on board ship, because every pound of fuel saved increases the cargo carrying capacity of the boat.

Another very important point, in which marine service differs from land service, is that the horse-power required to drive a vessel (within reasonable limits) increases as the cube of the speed. For this reason it is essential, in order to operate economically in the marine field, to develop maximum horse-power with as small equipment and as little weight as possible, and high-degree superheat offers a means of producing maximum horse-power with minimum weight of equipment.

It is to be regretted from every standpoint that so little progress toward higher economy has been made in our own marine service. The reason for this cannot be laid to the lack of examples of successfully operating equipments to secure such economy, because hundreds of ships have been successfully operated for years, with high-degree superheaters, in the merchant marine service of other countries.

In stationary service in this country, superheaters have been used for some twenty years, or more. However, taking into consideration the total horse-power capacity of industrial steam-power plants in this country, the percentage equipped with superheaters is comparatively small. From the information obtainable, it appears that not over 10 per cent. of the existing power-plants are equipped with superheaters. Approximate statistics of the

capacity of the steam power-plants in this country further indicate that only a small percentage of the central stations have utilized superheated steam; and, of these, only a few of the more recent ones have taken advantage of the economies of superheated steam by employing superheat of 200 degrees or upwards.

ECONOMY OBTAINED WITH SUPERHEATERS

In railway service, the steam superheater has without question revolutionized locomotive operation. The great increase in the economy of locomotives is well known. The high-degree steam superheaters now used have reduced the fuel consumption of locomotives, for the same power developed, an average of 25 per cent. This is remarkable, particularly when one considers that the steam consumption of a saturated steam locomotive averages about 30 pounds of steam per horse-power, whereas with superheated steam this is less than 19 pounds. The latest types of loco-

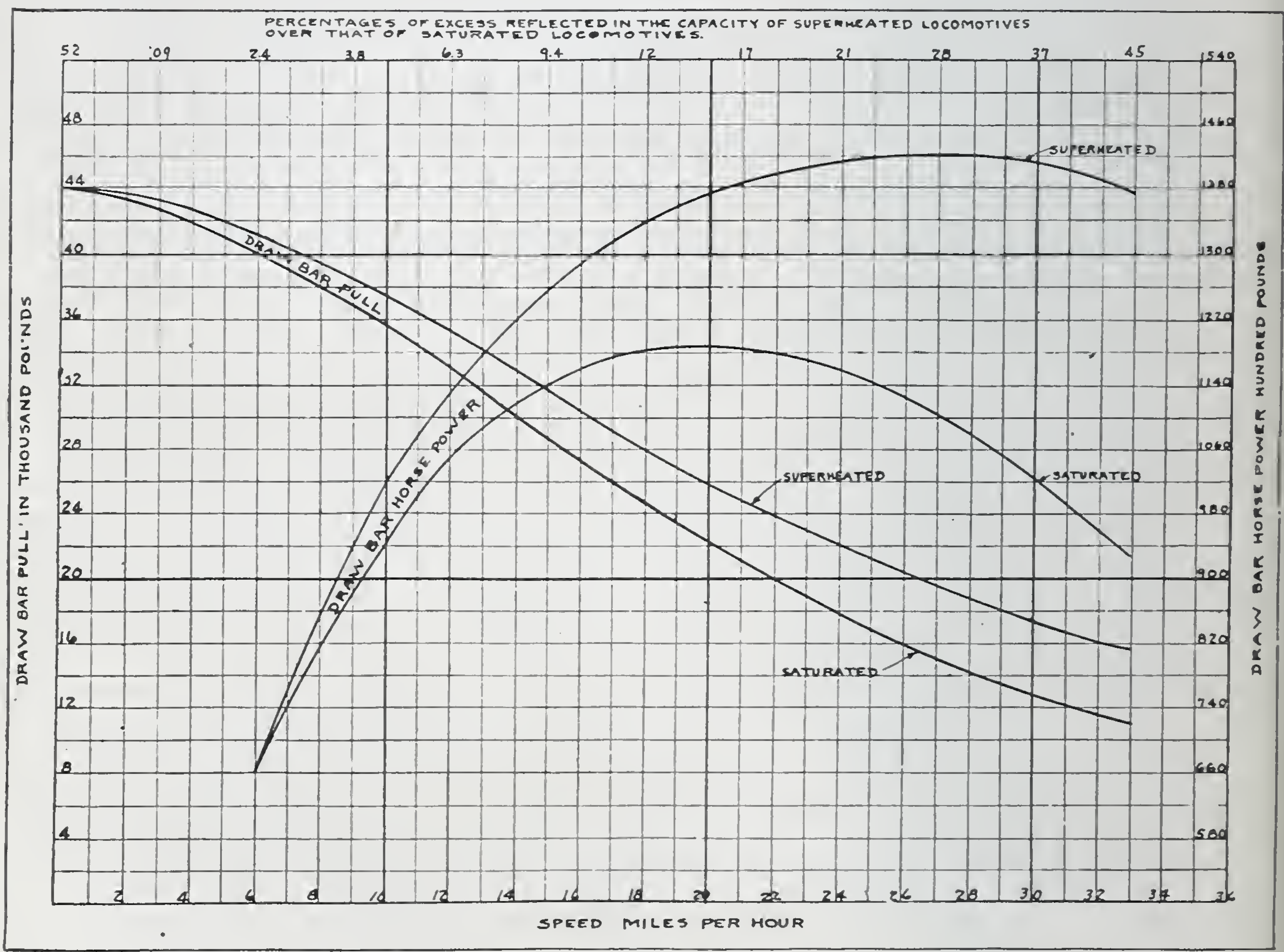

Fig. 1. Percentages of Excess Reflected in Capacity of Superheated Locomotive over Saturated Locomotive

motives are developing an indicated horse-power on less than 16 pounds of steam throughout the range of power, which often varies from 500 to over 3000 horse-power.

In marine service, results obtained have been equally satisfactory. A fuel saving of 18 to 25 per cent. is obtained in compound engines; 12 to 18 per cent. in triple expansion; and 10 to 12 per cent. in quadruple engines.

Superheating in stationary plants offers the same opportunity for economy, per unit of power generated, as in locomotive and marine practice. The increase in efficiency obtained by superheating is in nearly direct ratio to the degree of superheat used. At 100 degrees a saving of 8 to 10 per cent. in fuel is possible, depending upon the boiler and engine construction; at 200 degrees superheat, a saving of 18 per cent., or more, is possible. The increase in plant capacity by the use of superheaters is also a factor. To illustrate: A superheated plant delivering 200 degrees the same size. The application of superheaters to existing plants, therefore, is a very convenient and effective means of increasing the plant economy and capacity.

The increased economy is effected, in general, in four ways—by increasing boiler efficiency, by reducing condensation losses in steam lines, by reducing the steam consumption of the prime mover, and by increasing the capacity of the plant.

INCREASE OF BOILER EFFICIENCY

A definite amount of heat is required to superheat steam to a certain temperature, and this heat is furnished by the fuel. When a definite weight of steam is generated, additional fuel will be consumed to superheat this steam.

Let us consider a boiler designed without a superheater to give the highest practical thermal efficiency. Suppose we install a properly designed superheater in this boiler. It will be found that the overall thermal efficiency of the combined boiler and superheater will be greater than the boiler without the superheater when evaporating the same amount of water, because, by the addition of the superheating surface, more heat is absorbed and the superheat will develop sufficient steam with four boilers to generate the same power as a saturated plant having five boilers of

final uptake gas temperature is lowered. This result can be accomplished, however, only when the superheater is correctly designed so that it will not unduly obstruct the flow of the gases through the boiler.

ELIMINATION OF CONDENSATION IN STEAM LINES

Many power-plant installations are forced by local conditions to operate their prime movers at long distances from the boilers supplying the steam. The long pipe-lines carrying the steam are often run out of doors where they are exposed to all kinds of weather. These conditions naturally have a marked effect on the quality of steam when it reaches the point where it is to be used.

An advantage results from the fact that no moisture is carried over from the superheater, and also because the low thermal conductivity of the superheated steam prevents condensation. Superheating is advantageous not only from an economical standpoint, but also because it eliminates water-hammer and its attendant engine and pipe troubles.

It is a matter of historical interest that the first recorded use of superheated steam was necessitated by the condensation which took place in a long steam line.

Long existing pipe-lines carrying saturated steam can, without any change, be used for superheated steam, and this use will be followed by a great saving in the available heat and quantity of steam delivered for power purposes. This fact alone should make the use of superheated steam on the long pipe-lines universal practice.

When condensation in steam lines is reduced, both steam and coal are saved, because in the generation of steam, nine-tenths of the heat absorbed by the water in evaporating it and raising the steam pressure is latent heat. When steam is condensed, latent heat is liberated and unless it performs useful work, it is wasted. Condensation, therefore, occurring in pipe-lines represents an absolute waste of nine-tenths of the heat, and if the condensate is not returned to the boiler all the heat is wasted. A superheater is absolutely essential to raise the temperature of the steam to a point such that all of it may be transmitted to its destination and used without condensation losses.

IMPORTANCE OF SUPERHEAT IN STEAM-TURBINES

High-degree superheat is of vital importance in steam-turbines, and the steam-turbine is particularly adapted to its use. All turbine plants of any size are now installed with superheat, and some modern plants are using 250 degrees. Turbine manufacturers have made a strong point in favor of turbines, in that high superheat can be used. The most economical steam prime movers to-day utilize steam of 300 degrees superheat, or more. These turbines produce a brake horse-power for eight pounds of steam and on less than one pound of coal.

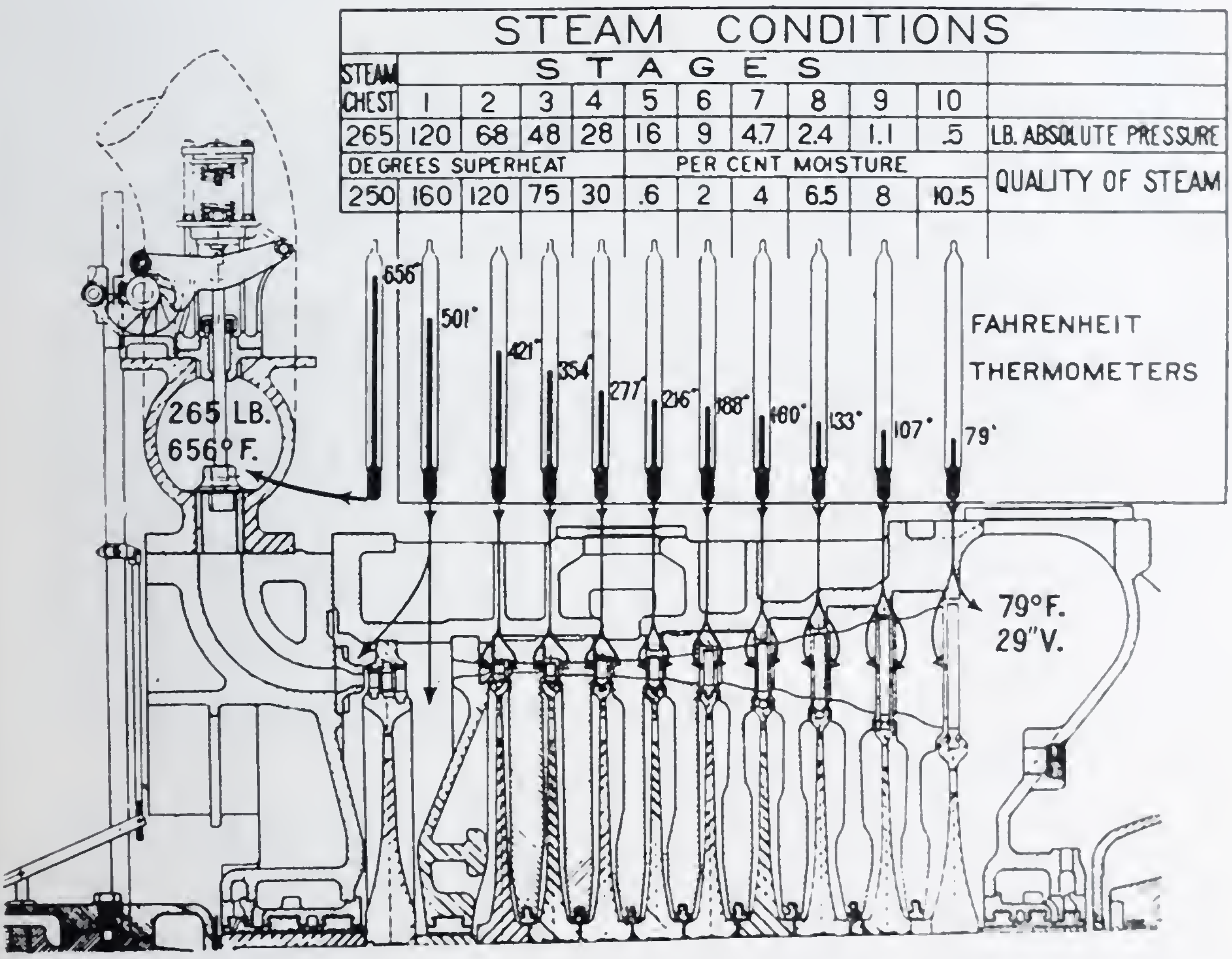

Fig. 2. Diagram Showing Typical Steam Conditions in Steam-Turbine. (From *General Electric Review*.)

The water rate of an economical steam-turbine will be reduced one per cent. for every 12 degrees of superheat up to 200 degrees. This figure is based on large and economical turbines. Small turbines, inherently less economical, show a greater proportionate saving with superheated steam.

The usual type of horizontal return tubular boiler with a comparatively large water and steam capacity delivers wet steam.

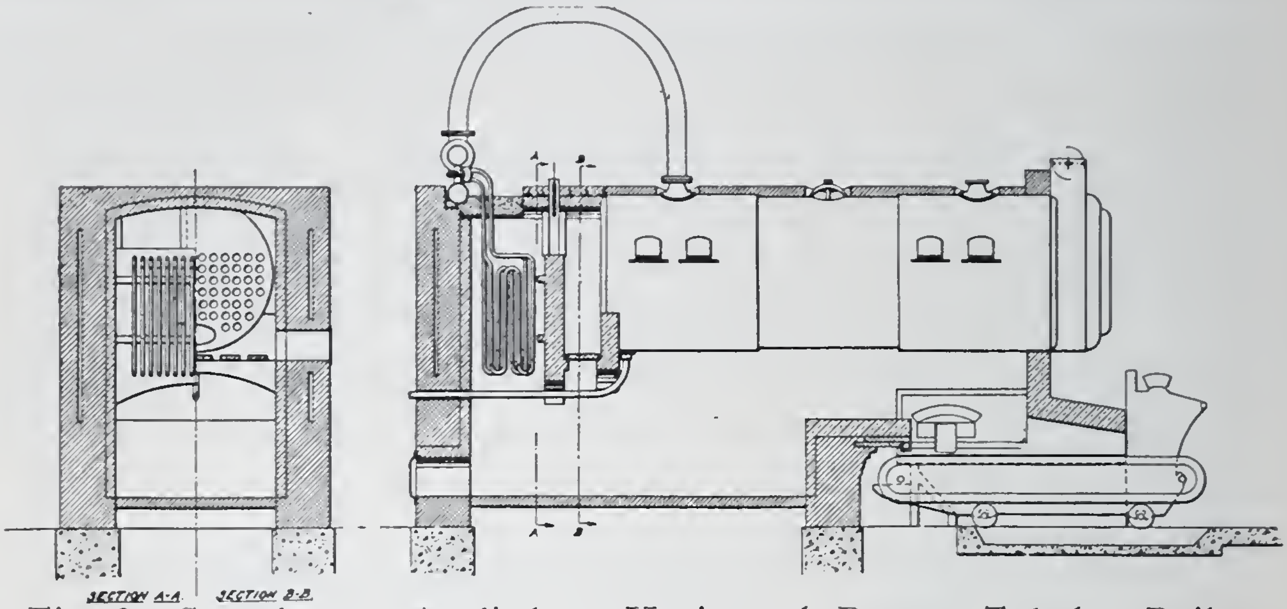

Fig. 3. Superheater Applied to Horizontal Return Tubular Boiler.

The modern water-tube boiler, with less water and steam space, is much worse. This condition is accentuated, particularly, by the fact that the modern water-tube boiler is forced to evaporate water at a rate three or four times that of the return tubular boiler, and the percentage of moisture in the steam from such a boiler is high. Such a condition is reasonable and might be expected. Take, for example, a 500-horse-power, water-tube boiler. At normal rating such a boiler will deliver 15,000 pounds of steam per hour. Conditions often arise when such a boiler will be called upon to evaporate 30,000 to 40,000 pounds of water per hour. Superheat takes out all the mositure that would otherwise be carried over and is, therefore, particularly beneficial when boilers operate at high capacities.

It is this moisture which is particularly damaging to steam-turbines. It reduces the efficiency by the excessive friction set up between the water and the turbine parts. One authority points out that a turbine without superheat is merely a form of water-brake—for every ounce of water passing through, no matter how finely divided, is inert material, and serves only to check the running of the machine.

The internal surfaces of the turbines are enormously increased beyond those in reciprocating engines, and the effect of temperature range in augmenting condensation is very great, even though the temperature in the turbine does not change so widely.

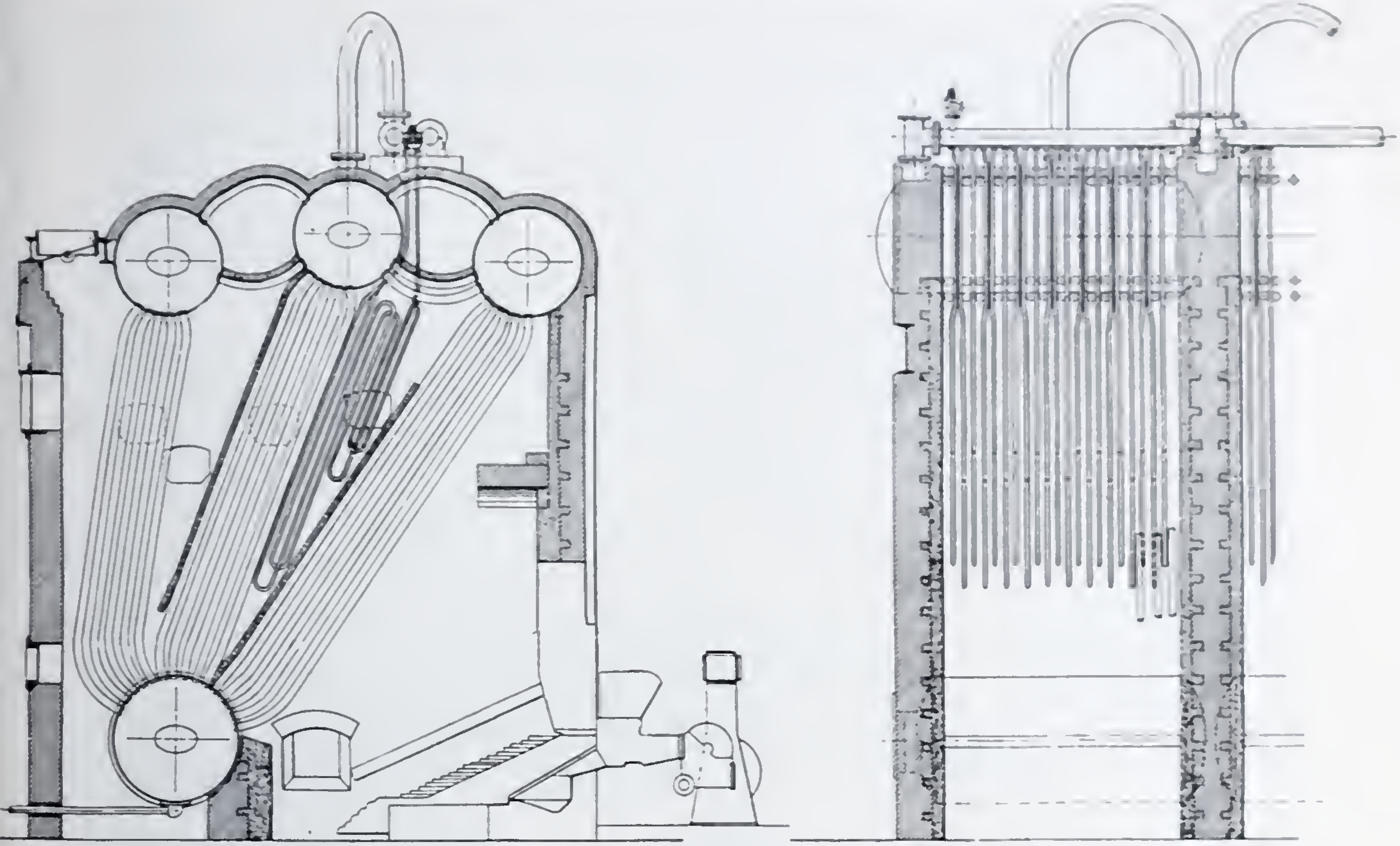

Fig. 4. Superheater Applied to Stirling Boiler.

The destructive effect of water and moisture on the turbine blading is too well known to require discussion. Erosion of turbine blades, due to water, is very rapid. The first effect of this erosion is immediately felt in increased steam consumption. Reblading on this account could have been avoided in many cases had superheated steam been used. A correctly designed superheater will take care of the mositure delivered from the boiler.

INCREASED EFFICIENCY OF RECIPROCATING ENGINES

Generally speaking, a steam-turbine will not benefit by superheat to the same extent as will the reciprocating engine. The saving to be expected by superheating is dependent on the amount of cylinder condensation that would occur in the same engine if no superheat were used. Evidently, the greater this condensation, the larger is the possible saving.

When steam is superheated 200 or even 250 degrees F., it can be exposed to the cooling action of the steam-chest and cylinder walls without condensation, and has 30 to 40 per cent. greater specific volume than saturated steam of the same pressure. For example, one pound of water at 170 pounds pressure, absolute, produce 2.68 cubic feet of saturated steam at a temperature

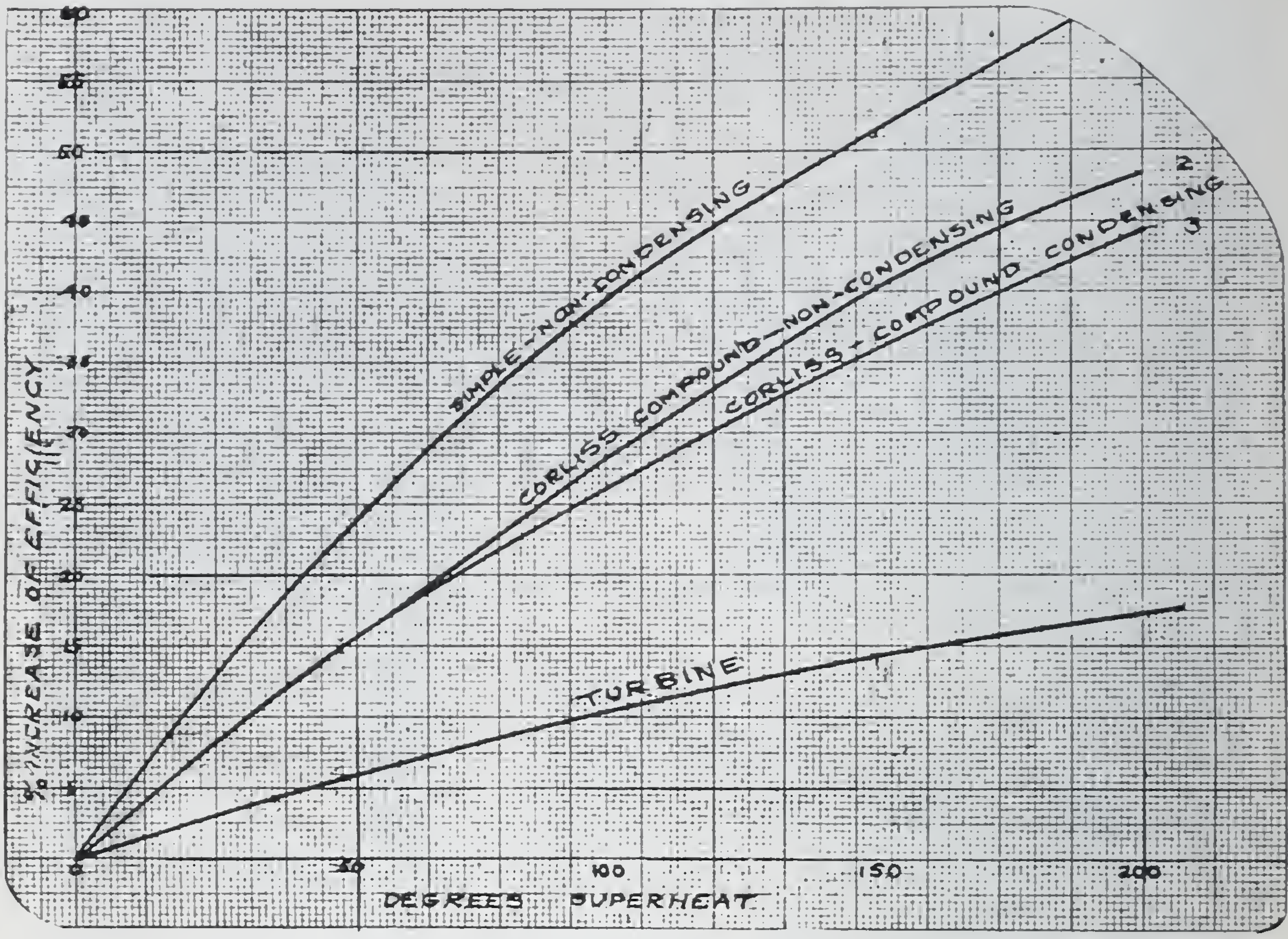

Fig. 5. Increase in Efficiency of Steam Prime Movers by Use of Superheat at Various Temperatures.

of 368 degrees F. After passing through the superheater and gaining 200 degrees superheat, the volume will have been increased to 3.54 cubic feet. A part of this increased specific volume is lost before expansion of the steam in the cylinder takes place, on account of the cooling section of the cylinder head, piston and cylinder walls. While the superheat in the steam entering the cylinder may be 200 degrees, the superheat of the steam at the moment of cut-off is considerably less. The entire elimination of all condensation losses, together with the remaining increased volume of the steam, effects substantial savings in the steam consumption per indicated horse-power hour, and in the fuel consumption as well.

DELAYED ADOPTION OF SUPERHEATERS IN STATIONARY PLANTS

There is no valid reason in theory, or practice, why new steam power-plants, no matter how small, should be built to-day without the application of a steam superheater delivering superheat of a temperature suitable for the plant. It is the plants with

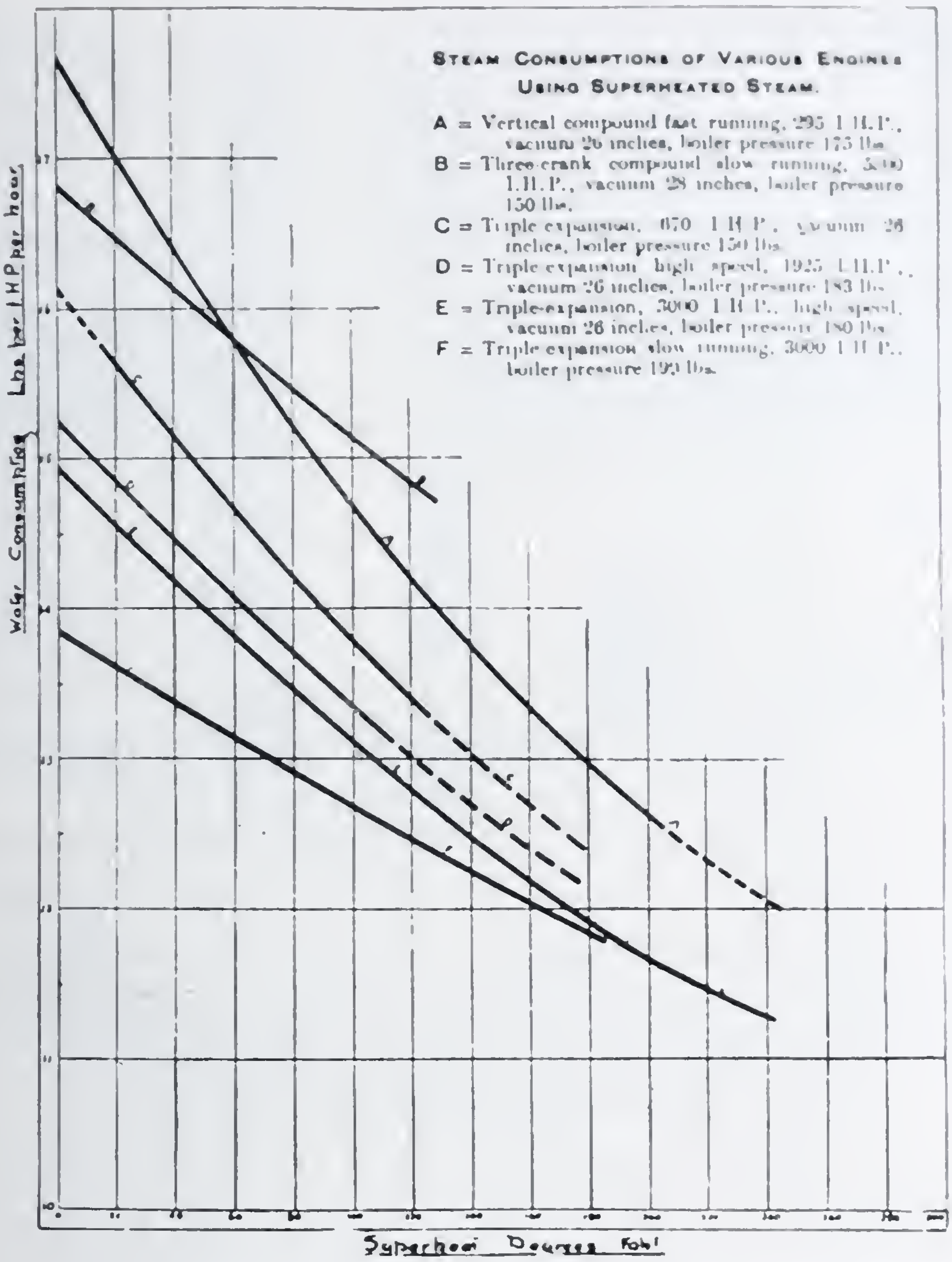

Fig. 6. Steam Consumption of Various Steam-Engines Using Superheated Steam.

small units that are benefited most by high superheat. Furthermore, a small, inexpensive, reciprocating engine or turbine can be designed to give very nearly the same economy for the same conditions, as is obtained in the large turbine plants. Why engines and turbines of small size designed for high superheat have not been put into general use in this country is difficult to understand, as there is nothing in the design of boilers, engines, or auxiliary equipment that presents difficulties.

The peculiarity of the present situation is that it is the turbine plants with units of 20,000 to 60,000 kilowatts capacity that are utilizing high superheat; but the smaller units—which, it would seem, could be very cheaply designed for high temperatures—are

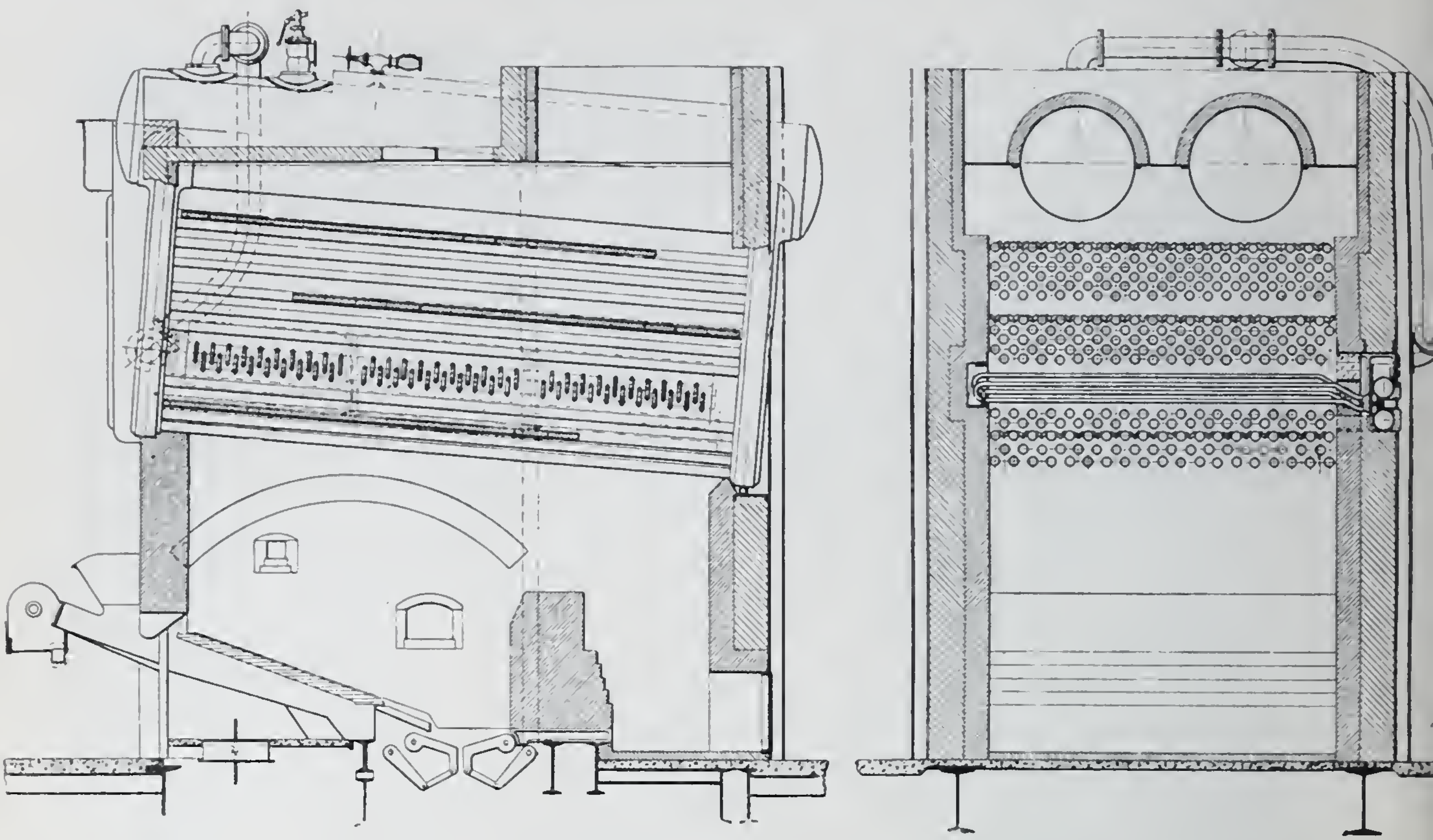

Fig. 7. Superheater Applied to Heine Boiler with Horizontal Baffle.

operated with saturated steam, or with low-degree superheat.

It would appear to be poor economy, when designing moderate size isolated plants, to limit the superheat to about 100 degrees in order to avoid the use of cast-steel fittings—which construction, it is claimed, is necessary for higher temperatures. Assuming, however, that it is necessary to use cast-steel fittings, the fact remains that the increase in economy and capacity by designing the power-plant for 250 degrees superheat will more than offset the additional cost of the larger superheater and the other changes in construction necessary on account of increased temperature.

In the same manner that superheaters are justified in the construction of new power-plants, their application to existing plants is warranted. It is a fact that the majority of isolated plants are still operated as saturated plants; and, as probably 20,000,000 horse-power of such plants are now in operation, an enormous saving of fuel could be obtained if a properly designed superheater were applied. It is true that it may prove impracticable in many cases to use high degrees of superheat in old plants, but it is equally true that there are few plants which cannot be operated entirely satisfactorily with 100 to 125 degrees superheat, using present equipment.

An argument often used against the application of superheat-

ers in old plants is that the air-compressors, engines, or pumps are not suitable for handling superheated steam. It is true that this equipment may give trouble when operated with a superheat of 200 degrees, or more, but experience has shown that no difficulty presents itself in the satisfactory operation of slide-valves or Corliss valves up to 125 degrees.

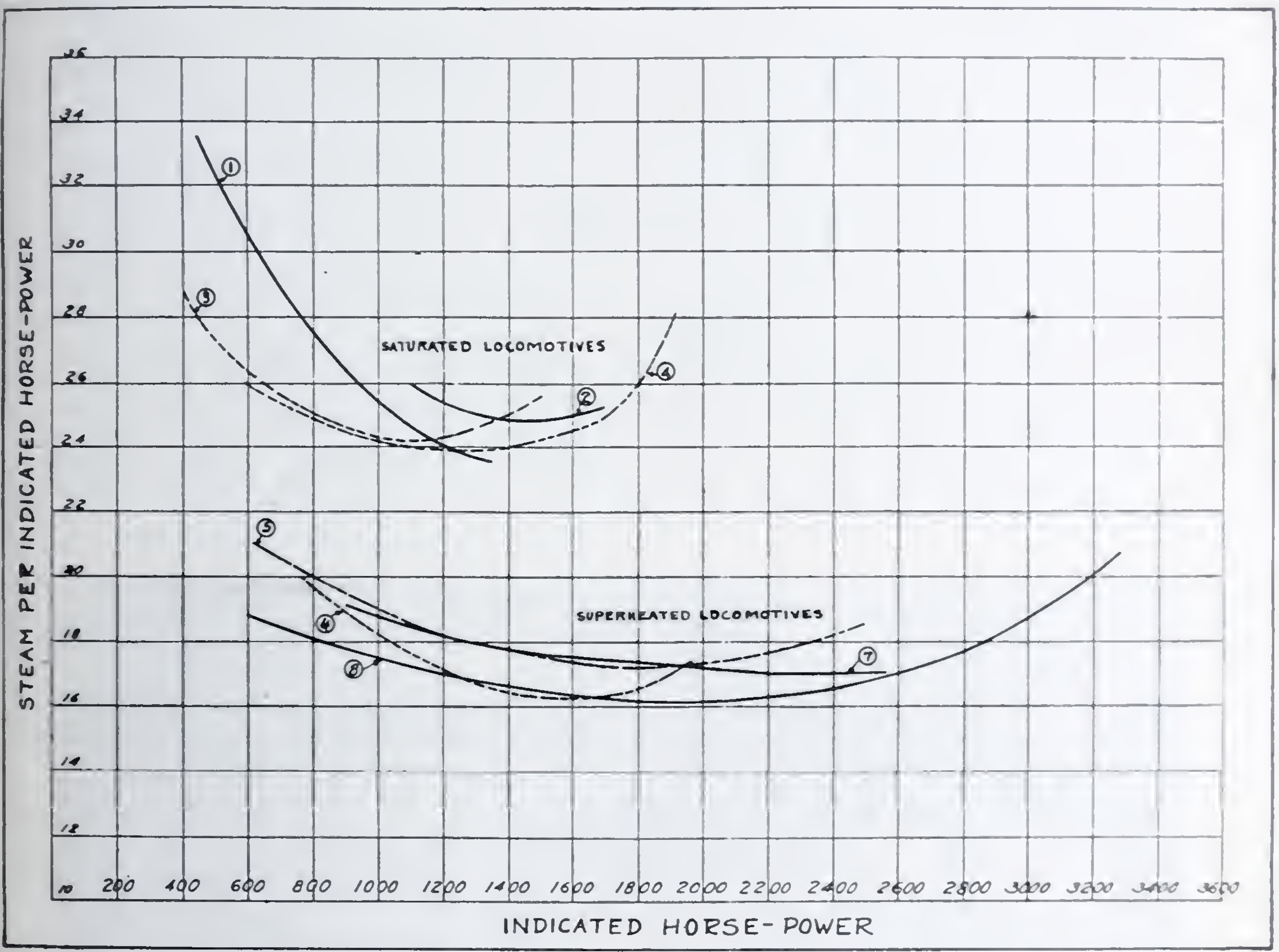

Fig. 8. Steam Consumption of Locomotive per Indicated Horse-Power—Saturated vs. Superheated.

With reference to lubrication, the operation of reciprocating engines with superheat continues successfully, not only for 100 or 125 degrees but for 250 to 300 degrees. For example, there are to-day over 65,000 locomotives operating with at or above 200 degrees superheat in all parts of the world, with satisfactory lubrication.

The question of piston-rod and valve-stem packing is another point usually brought up. All modern superheated locomotives are equipped with piston-valves, which have proved eminently

satisfactory, and poppet-valves on stationary engines have also been successful when superheated steam has been used.

The condition of the steam-piping and the use of cast-iron fittings are often mentioned in connection with the application of superheaters to existing plants. Investigation has shown that a high grade of cast-iron or semi-steel is satisfactory for superheated steam. It is quite true that high-grade cast-iron or semi-steel has an ultimate strength of only 30,000 pounds per square inch, as compared with 50,000 pounds for cast-steel, and, therefore, more material is necessary to obtain the necessary strength, but when one considers the extraordinary difficulties met with in the construction of cast-steel valves and fittings and their high cost, it does seem that high-grade cast-iron or semi-steel fittings of adequate dimensions would be more economical than cast-steel and equally as safe. It is heard, now and then, that failures have occurred in piping where superheated steam has been applied, and these failures are laid to the so-called growth of cast-iron. Very

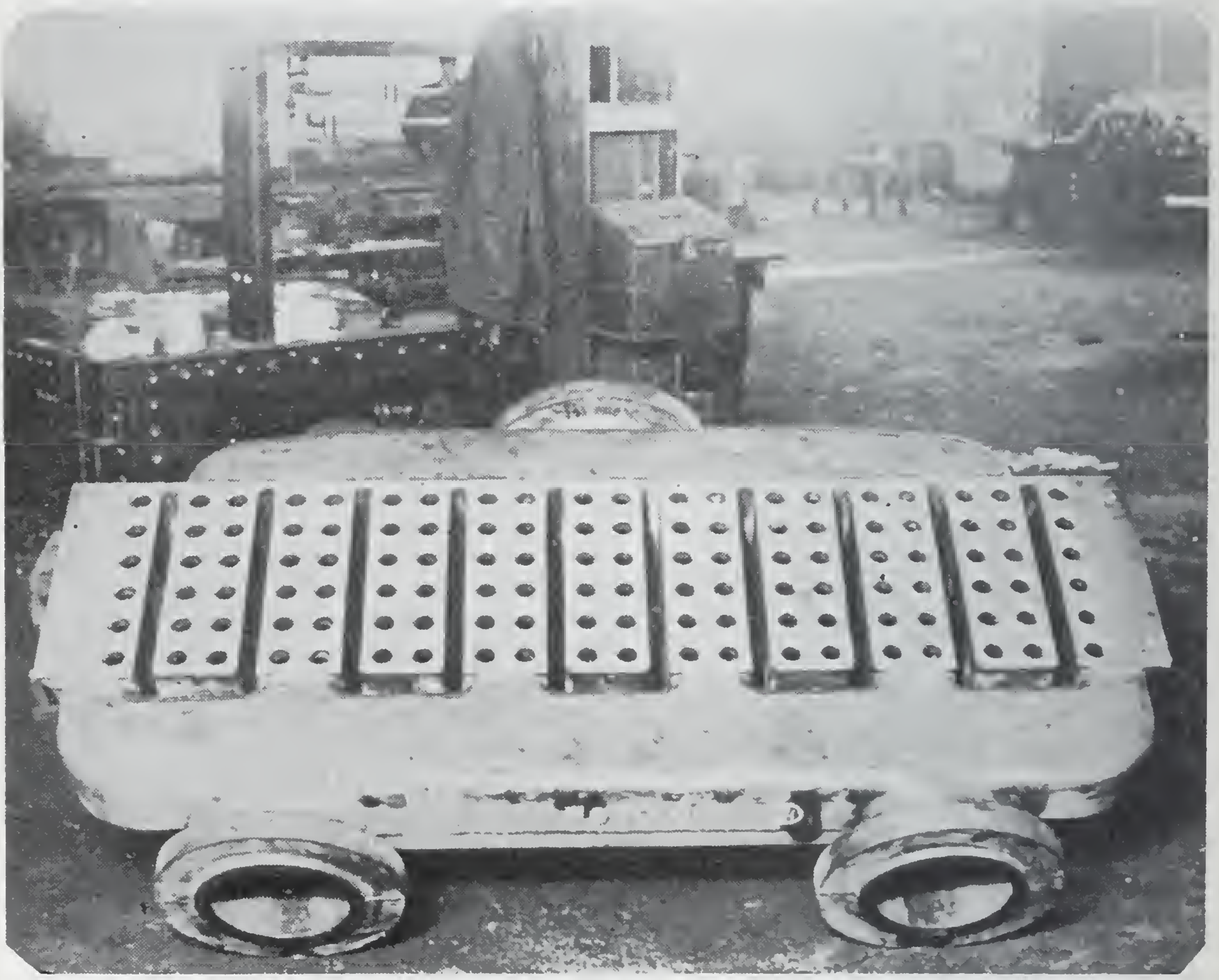

Fig. 9. Çast-Iron Header for Superheater Used in Locomotive Practice.

little, if any, evidence has been published to prove that this was the cause of the failure, but on the contrary most of the troubles are traceable to lack of provision for the increased lineal expansion.

It may be of interest to state that there are in operation to-day over 37,000 locomotives in this country and 28,000 in other countries, using 200 pounds of pressure and 200 or more degrees superheat—a total steam temperature of 650 degrees—where the heaters and collector castings, even though of large and difficult construction, are made of high-grade cast-iron. There are no failures of these installations which can be traced to the action of the superheated steam. As a matter of fact, this high-grade cast-iron has proved absolutely satisfactory, although it has to withstand the rapid fluctuations of steam temperatures up to 750 degrees and is subjected at the same time to high gas temperatures. This severe condition will never have to be met with in the valves and fittings in stationary plants.

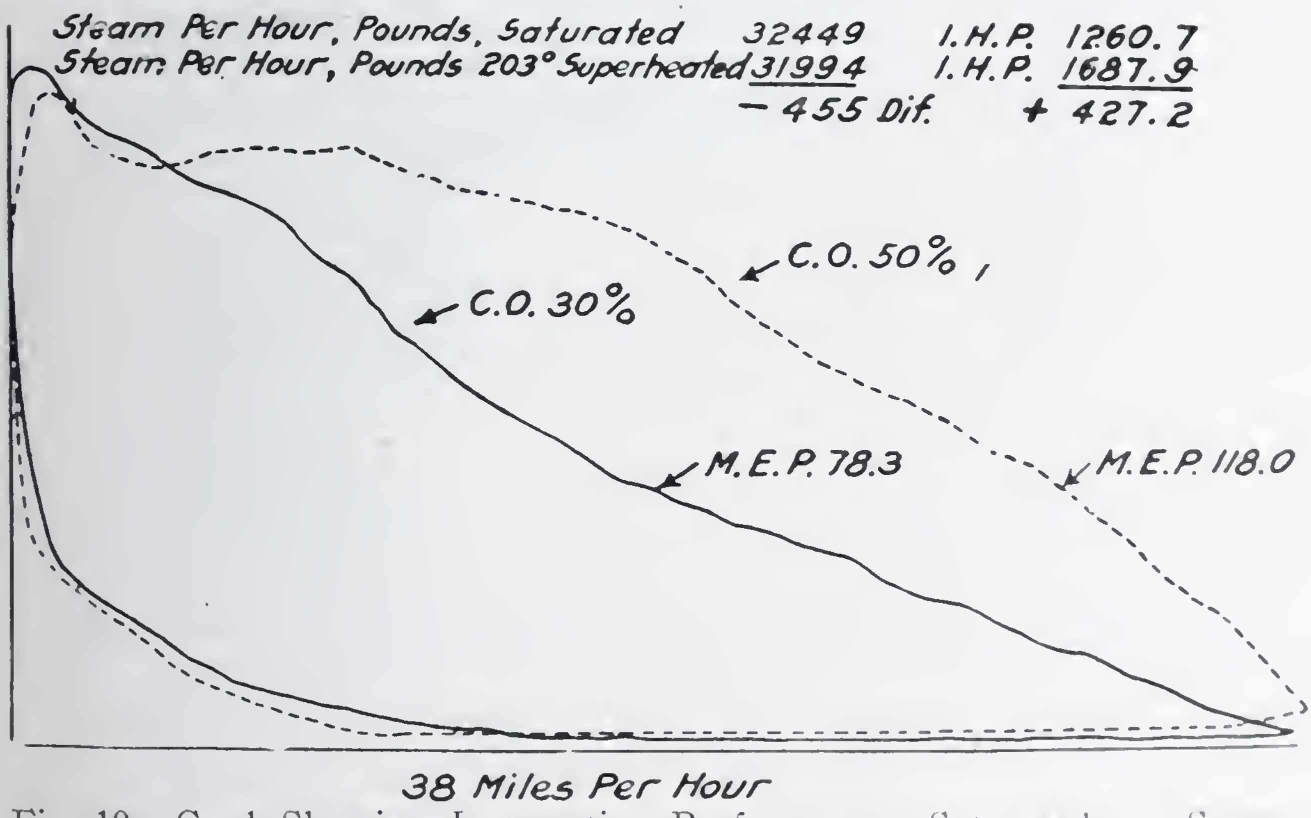

Fig. 10. Card Showing Locomotive Performance—Saturated vs. Superheated. (From *P. R. R. Bulletin.*)

All the cylinders and steam-chests, and the steam-pipes between them and the superheaters on locomotives are made of ordinary cast-iron, and failures of such parts are no more frequent than where saturated steam is used. It seems, therefore, that the

present prejudice against the use of superheated steam in existing plants is the result of incorrect investigations into occasional failures.

To sum up the situation, any existing power-plant equipped with any type of boiler and utilizing any type of turbine or reciprocating engine can satisfactorily use from 100 to 125 degrees superheat. While this increased steam temperature will not be as beneficial as the higher temperatures, even such moderate degrees of superheat are capable of producing economies of 15 per cent., or more.

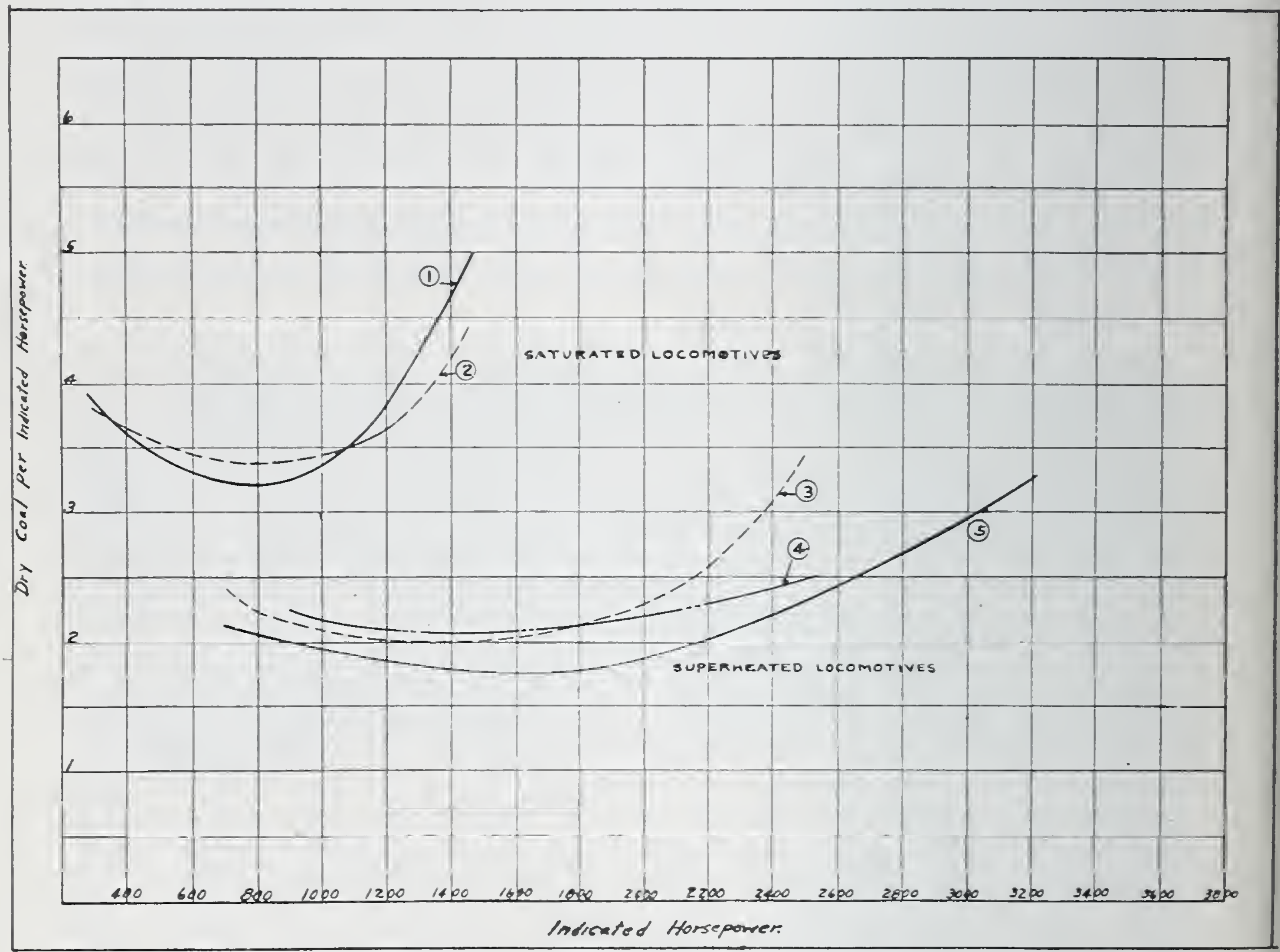

Fig. 11. Coal Consumption of Locomotive per Indicated Horse-Power—Saturated vs. Superheated.

DESCRIPTION OF VARIOUS TYPES OF SUPERHEATER

The apparatus used in the generation of superheated steam can be divided into two classes; namely, the independently fired superheaters and superheaters installed within the boiler setting.

The independently fired superheater is not widely used, due mainly to the smaller saving effected in the fuel bill as compared

with that produced by the superheater located within the boiler setting. However, there are many places where it is convenient and advisable to use it. In many plants it is desirable to have a small amount of steam superheated to a high degree and for such cases the independently fired superheater has proven most satisfactory. In places where waste gases of a high temperature are available, it has proved to be the proper installation. With the advent of the compound turbine it is quite possible that the independently fired superheater will be used to superheat the steam between the high- and low-pressure elements. In general its use is confined to special and limited cases.

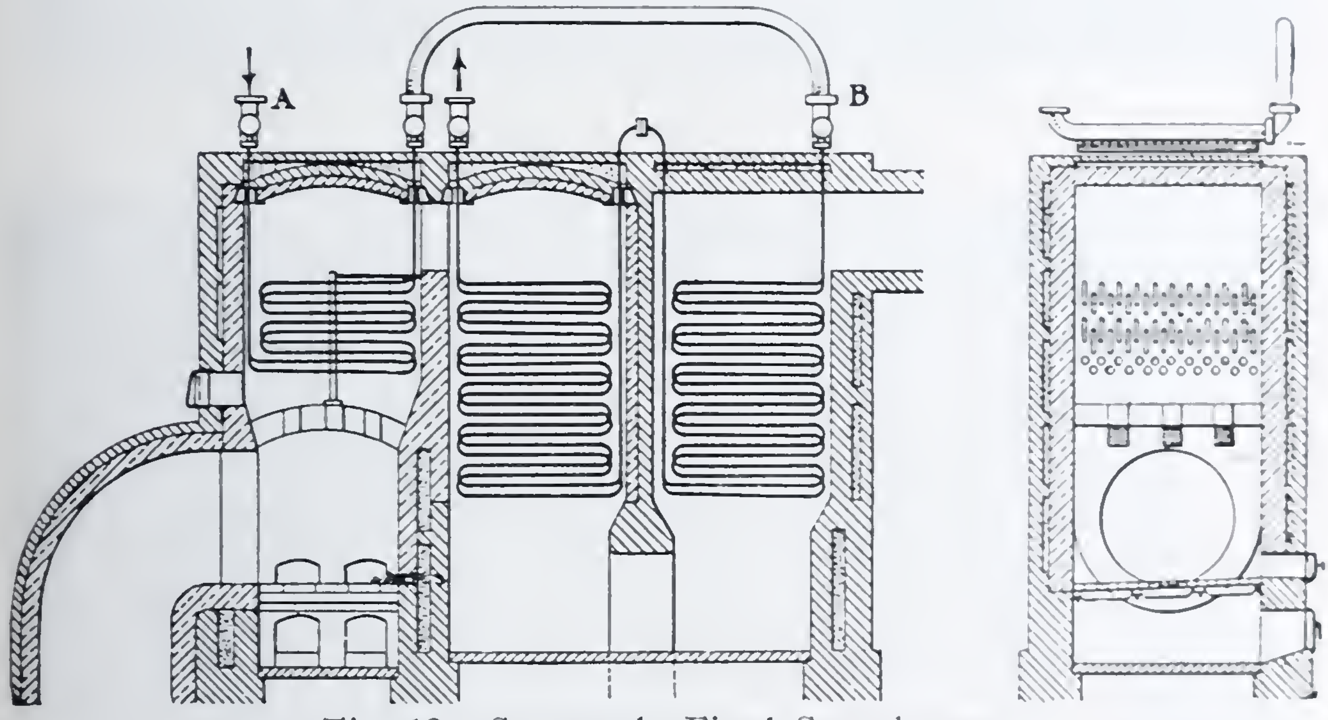

Fig. 12. Separately Fired Superheater.

The superheater installed within the boiler setting is the one most generally used. The superheater thus installed operates much more economically than the independently fired superheater. The opportunity for heat losses by radiation is not increased over that of the boiler setting itself. It can be so placed in the gas passes that it will be subjected to the most desirable temperature and will not be subject to deterioration by too high temperatures, or to ineffective operation by too low temperatures. The important factor of a superheater installed in the boiler setting is that it be correctly and carefully designed, and located so that it will deliver continuously the desired amount of superheat. The design and location of the superheater in the boiler setting require

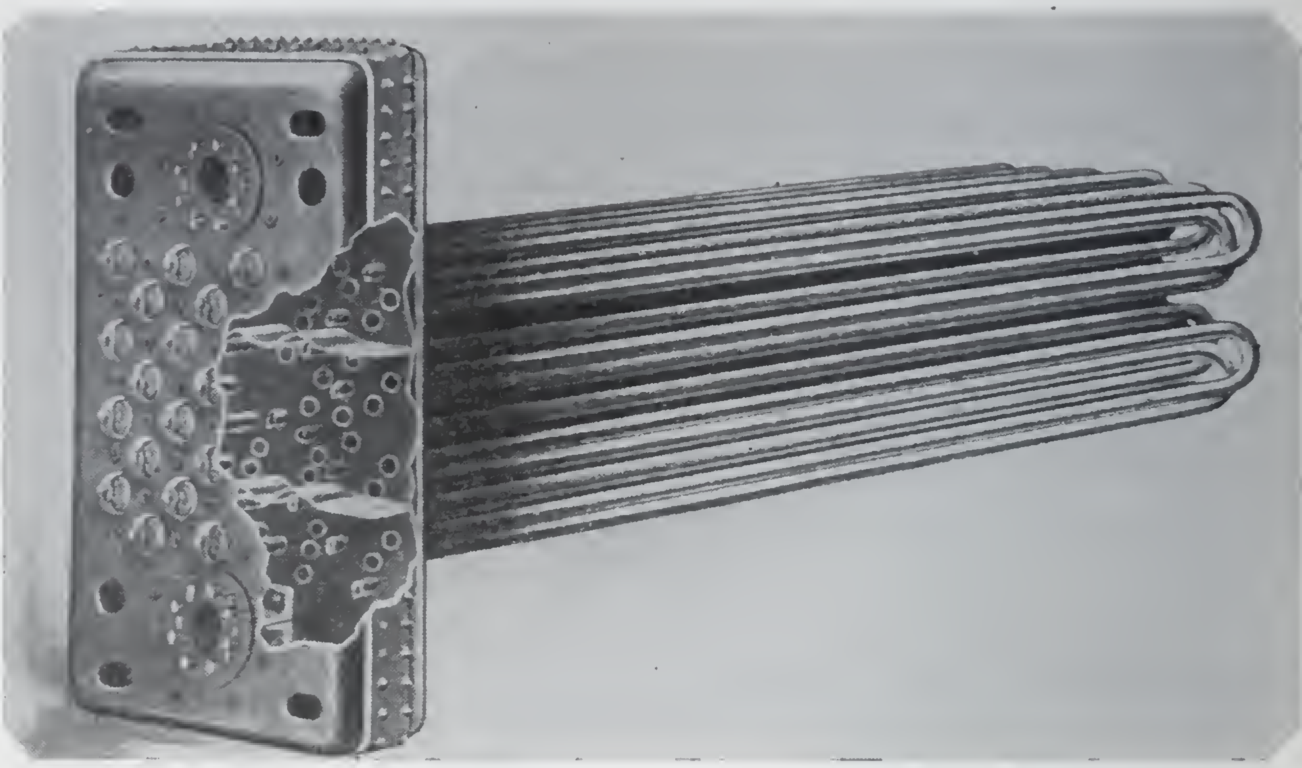

Fig. 13. "Heine" Superheater.

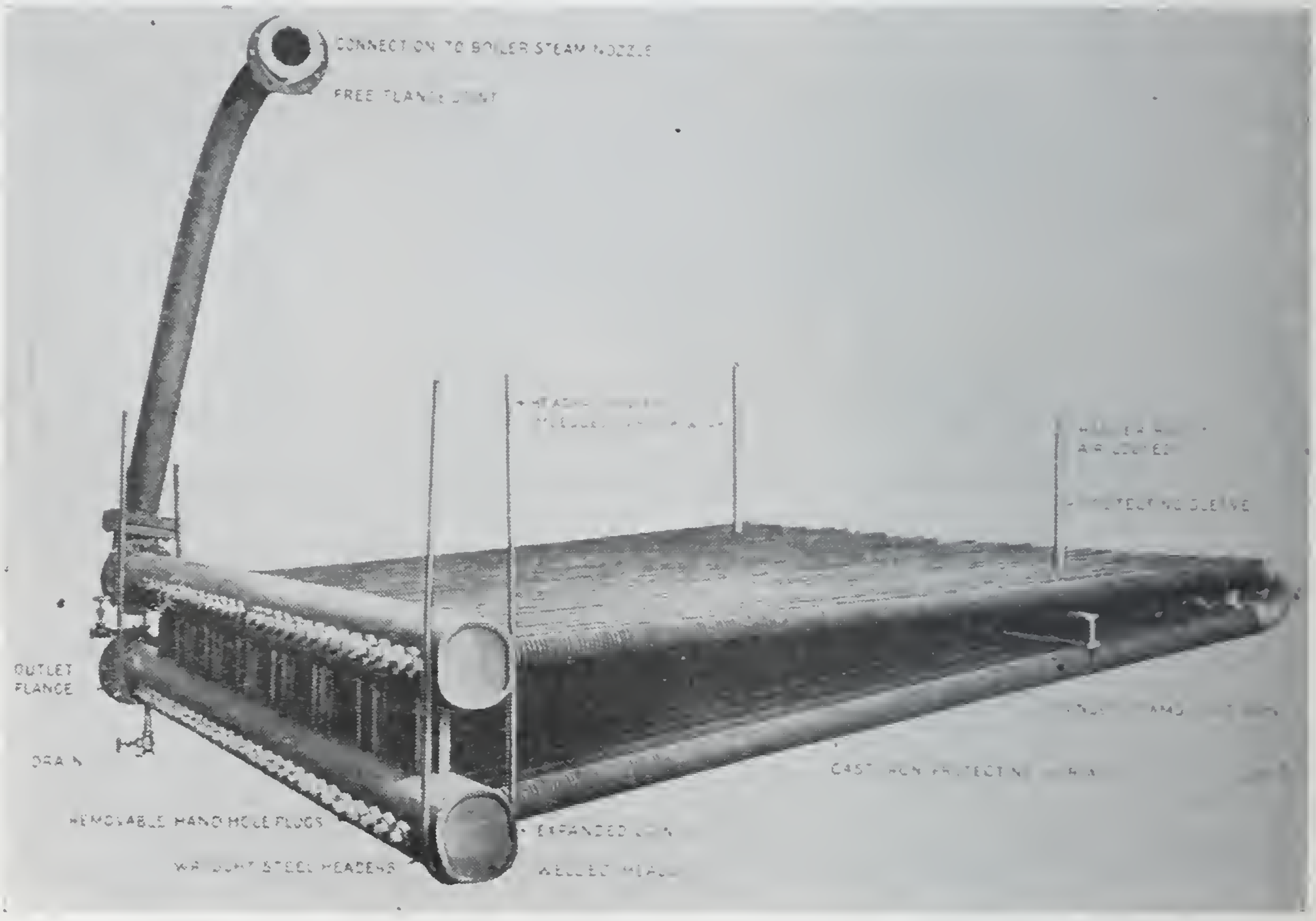

Fig. 14. "Foster" Superheater.

REQUISITES OF IDEAL SUPERHEATER

just as much study from an engineering standpoint as the boiler, engines, and other equipment which constitute the plant.

An ideal superheater to operate economically and efficiently, as well as to constitute a practical superheating apparatus, should possess the following features:

1. Accessibility for inspection and repairs.
2. Safety and security of operation.
3. Protection again overheating, insuring maximum life.
4. Maximum superheating efficiency.
5. Improved efficiency of the combined boiler and superheater.
6. Proper consideration of steam velocities and steam areas to give minimum drop in steam pressure.
7. Uniformity of superheating, and possibility of regulation.
8. Correct arrangement for expansion and contraction of all parts.
9. Provision for keeping units free from soot and ashes.
10. Minimum possibility of leakage.
11. Greatest flexibility in adaptation to different designs of boiler.

The feature of complete accessiblity is, of course, quite important. The units should be made of seamless steel tubing and attached to the headers, so as to be capable of quick and easy

Fig. 15. "Elesco" Superheater Tube.

removal. The superheater headers, which are required for the distribution and collection of steam, should be located, whenever possible, outside of the boiler setting so the headers and joints can be examined and repaired from the outside. Such a feature is indeed a great advantage, as there will be no possibility of leaks remaining undiscovered, reducing the draft, efficiency, and capacity, and causing mechanical troubles. A very important advantage of locating the header outside of the setting is that it will not be subjected to the hot gas temperature in the boilers. In superheaters where the inlet of the saturated steam and the outlet of the superheated steam are on the same side of the boiler, a

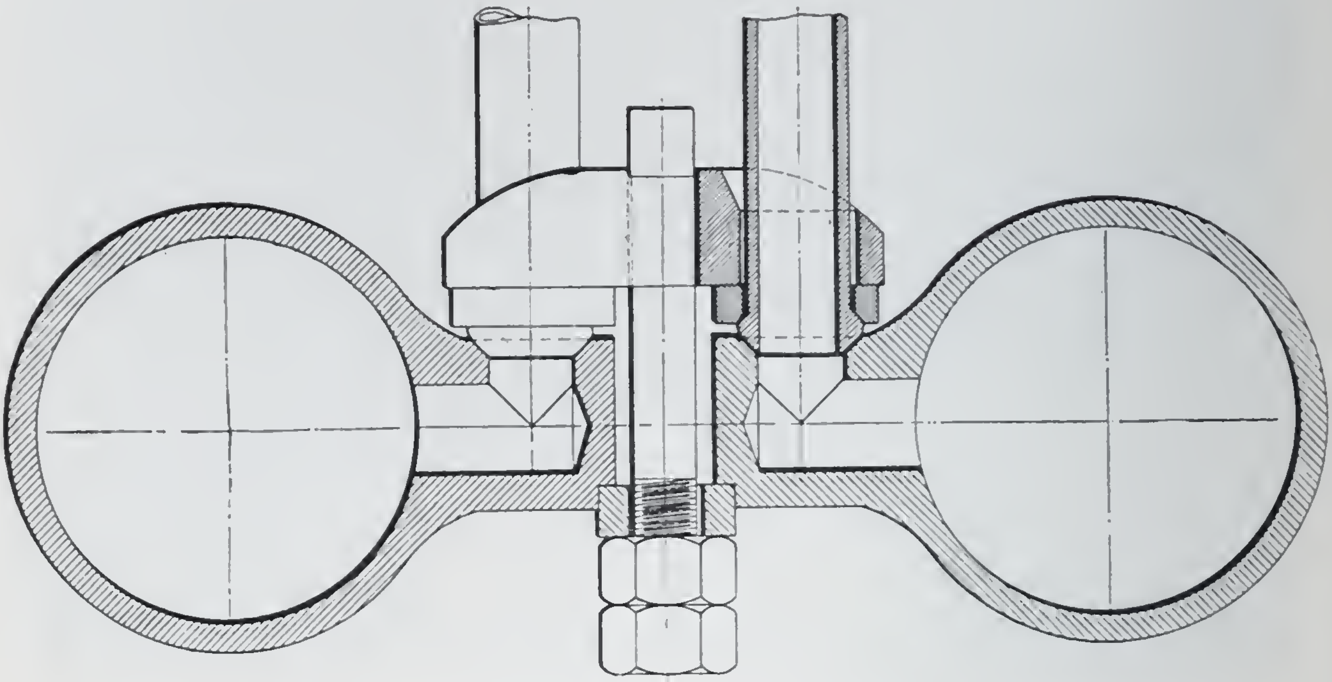

Fig. 16. "Elesco" Superheater Header, Showing Tube Connection.

short-circuiting of the steam at the outlet occurs. The result is that very little steam is flowing through the units furthest away, and they, as well as the header, may become overheated; particularly the header, as even at full loads the steam flow is not sufficient to carry away the heat.

With reference to safety, only construction of the best and most reliable design should be used in superheaters, as they are subjected to very severe service. Wherever possible, the superheater should be located in such a position with reference to the boiler that the temperature of the gases passing over the superheater will not be too high. This is most easily accomplished by so locating the superheater that the gases will have traveled over certain portions of the water heating surface before they reach the superheater, so as to reduce the temperatures considerably.

Where it is impossible to locate the superheater as above mentioned, and where the units will be exposed to the direct action of the furnace temperatures, they should be protected from overheating by controlling the gases flowing past the superheater, by means of damper construction. Such construction not only protects the units from overheating when steam is not flowing through them, but also serves as a means of regulating the temperatures for various ratings, and such constructions have been used with satisfactory results.

Maximum efficiency of superheating is obtained by locating the superheating surface in as hot a temperature zone as possible, with due regard to the necessary protection against overheating. It is also necessary so to proportion the superheater as to give correct relation between the steam area and the heating surface of each individual unit. The steam areas must not be so small as to produce an undesirable pressure drop, nor so large as to permit carrying over moisture, and even water, under certain operating conditions.

The steam should be brought into intimate contact with the gas-touched heating surface, to obtain a minimum resistance to the flow of heat from the gases to the steam. As a general statement, one of the important factors in superheating steam is the transfer of heat from the inside, or the steam-touched surface of the units, to the steam. The comparatively low specific heat of superheated steam, and its small heat absorbing capacity as compared with water, make the consideration of the steam-touched heating surface a subject of importance.

In all types of boilers, the superheater should be installed in such a manner as to compel the gases, after leaving the superheater, to flow past additional water evaporating heating surface. Such a location is advantageous because the temperature of the steam after being superheated is higher than the water temperature, and the gas temperature on leaving the superheater must therefore be higher than at the boiler uptake. This results in a higher combined efficiency than would be possible were the superheater located in such a way that the gases passed directly into the stack after leaving the boiler.

In the design of superheaters, careful consideration should be given to individual conditions of furnaces, fuels, and operating factors. The end in view is always to obtain uniform superheating effect without sacrificing simplicity or practicability. With correct location of the superheater in the gas path and proper distribution of the steam through the units under all loads, variations in superheat will be negligible. Uniformity in superheating should be further insured by using unit construction that will give minimum opportunity for the collection of soot and ashes.

Owing to the wide variation in temperature, considerable expansion and contraction of the superheater parts occur. This variation should be taken care of in the superheater design by providing maximum flexibility.

DISCUSSION

Mr. W. E. Snyder:* I cannot give an extended discussion of this paper for the reason that my experience with superheaters is not very extensive. I consider the paper a very good argument in favor of the superheater, but the argument would be strengthened a great deal if more data were given from actual installations in operation, with references to the source of the data. The latter point is, I think, of particular importance, because, when an engineer looks over certain figures, in the effort to make up his mind as to whether or not he shall recommend a certain thing, he always wants to know how those figures were obtained. Are they the results of pencil and paper calculations, or are they from actual tests; and, if from tests, what are the conditions? It is important, too, to emphasize the operating side with reference to what troubles, if any, are due to the use of superheaters. I can touch on only a few points in connection with actual installations.

I have no experience with the use of superheaters on locomotives, but have read considerable that is very favorable.

I do not think anyone questions the advisability of using superheated steam with steam-turbines, where the conditions are much more favorable to its use than they are with reciprocating engines. There are no problems of lubrication, of rod packing and of cast-iron moving parts in sliding contact. The question which does come up, however, in providing superheated steam for turbines, is, how high shall the superheat be carried? In my own mind, I had fixed 250 pounds pressure, with 150 degrees superheat, corresponding to a temperature of about 556 degrees, as a practical safe limit for such installations as are made in fairly large steel manufacturing plants. It may be that I am too low in this, but, if so, I am very willing to be shown. The condition we are after is a maximum operating efficiency, with a minimum of the troubles incident to operation. We do not want to add

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to an installation any features which may require special supervision and additional work from the men in charge. Just how high to superheat steam for an industrial steam-turbine plant is a question which will have to be answered largely by the companies building superheaters and steam-turbines, as they have a much more comprehensive experience to draw from, than has the ordinary operating engineer.

With reference to the advisability of installing superheaters in the older boiler plants, which supply steam mainly to engines and pumps, there is a good deal that can be said on both sides. Usually it is not a simple matter that can be figured out with pencil and paper, and the actual results obtained are not always as good as anticipated.

I have in mind one such installation made 11 years ago, where the superheat guaranteed was 125 degrees and that actually obtained was 90 degrees, with water-tube boilers of the Babcock & Wilcox type. One of these boilers was isolated and connected to a 250-kilowatt, cross-compound, high-speed, electric power unit, operating to about its capacity. The distance from the boiler to the engine was about 120 feet. Very careful 10-hour tests, with and without the superheater, were made, the actual fuel saving shown being 7¾ per cent. Afterward, similar practical operating tests were made, each running eight days, and the fuel saving shown was 6 2/3 per cent.

In another series of tests with which I am familiar, superheated steam was compared with saturated steam used in simple high-pressure, and cross-compound condensing blowing engines. The actual reduction in heat consumption by the engines varied from 4.4 to 6.9 per cent., while the actual reduction in fuel required varied from 23 to 26.7 per cent. The reason for the very high fuel reduction, as compared to the low reduction in the quantity of heat required by the engine, was due to the effect of the superheater in improving the efficiency of the boilers. In this case, the stack temperatures were very high and the superheaters were located between the boiler and the stack, so that the heat utilized by the superheater was reclaimed from what would other-

wise have been wasted. Of course, under such conditions, the superheater made a fine showing.

In two other recent installations of superheaters with which I am familiar, one designed to superheat 150 degrees and the other 100 degrees, there has been a great deal of trouble due to water in the steam. This water is carried from the boilers through the superheaters, and this is due to the character of the feed-water used. The water is not especially bad, but when a certain limit is reached in grains per gallon of foreign substances in the water in the boiler, water is carried over as explained. This is no argument against the superheater and is mentioned here only to make plain the fact that the installation of superheaters does not, by any means, insure superheated steam. The responsibility for water in the steam cannot be definitely thrown upon the boiler people, because they, in turn, can throw it back to the feed-water supply, and there is no practical system of water purification now in use in steel manufacturing plants, which completely eliminates all foreign substances in the water. Part of these substances is removed and most of the remainder changed to soluble compounds which go into the boiler just the same; therefore, the superheater engineer must have the assistance of the engineers connected with the boiler company and the water purifier company, in making the conditions such that the theoretical benefit of the superheater can be actually obtained.

As is emphasized in the paper, superheating is a real benefit when the steam is to be transmitted long distances. In one such installation, steam at 175 pounds pressure and 150 degrees superheat is carried nearly 4000 feet where the steam is mixed with saturated steam from other boilers and used in engines. The results have been generally good, with no troubles of any kind and practically no loss in condensation in the long pipe.

I think it is a mistake to argue in favor of 150 degrees superheat in old piping systems with cast-iron valves and fittings. I know that there used to be a great deal of discussion about the possible effect of superheated steam on cast-iron, and I believe that those reputed effects were very much exaggerated. In sev-

eral installations with which I have been familiar, where steam superheated 100 to 125 degrees was used in old pipe systems, I do not recall one instance of the distortion of cast-iron parts. This is not the point, however. Cast-iron under steam pressure is a treacherous material, especially when it may be subjected to external forces due to the arrangement of the piping. There is no use in adding to the risk by gradually pushing up the temperature of the steam.

It is not always a question of obtaining good cast-iron, as is recommended in the paper. Sometimes a core may shift, making one side of a fitting much thinner than the other. For all ordinary conditions of service this may never be known; but, if some additional influence be introduced, the result may be a disastrous failure of the weak piece. I do not believe in taking any additional risk in using cast-iron, in order to gain a slight increase in efficiency. This question is wholly apart from that of using superheated steam in new installations. In new plants, I am certain that the piping and all other parts can be made safe for 600 degrees, and probably for much higher temperatures. Where part of the piping and equipment is old, however, I would go mighty slow in pushing up superheat.

A point which I think should be covered by this paper comes up in connection with plants where high pressure and high superheats are advisable for most of the steam produced, but a smaller part of the steam is to be used in older piping and engines. How shall the temperature of this smaller part of the steam be reduced, so that the boiler plant shall be kept as simple as possible and still permit each kind of steam consumer to get the steam best suited to its requirements? This point comes in exactly in the same way as the water purification matter, previously mentioned. It is desired to obtain the most benefit possible from superheated steam. What shall be done in plants where not all of the equipment is adapted to the high temperatures required for the most modern part?

Another point which ought to be covered in the paper, is how best to clean the superheaters, externally and internally. With a modern tube-blowing equipment installed permanently in boiler settings, there will probably be no more difficulty in keeping the

external surface of the superheater clean, than is experienced with the boiler heating surface. Internally, however, the conditions are different, as the tubes are small and bent. I have been in boiler drums where the sides of the drums, at the water line, were covered with a layer of nice black soil, over an inch thick. I have seen this same stuff in engine cylinders and carried clear through engines into turbines using the exhaust steam. Where such conditions exist, what will happen with superheaters? Filtering the water with good sand filters will not wholly prevent the trouble. There must be some easy way of cleaning the superheaters internally. How shall it best be done?

Summarizing the above, superheaters seem to be well adapted to locomotives and a most advisable part of modern turbine installations. Their general adoption, however, in existing boiler plants embodying old equipment, is a matter which must be approached with great care. Sometimes their installation in such plants is really beneficial, but sometimes we are again impressed with the wisdom of the old adage that "all is not gold that glitters."

MR. JOHN PRIMROSE:* The very interesting paper of Messrs. Pendleton and Brandt treats the subject broadly, so it may be of interest to state what has been accomplished by superheating in a few specific cases.

The steam consumption of an Allis-Chalmers cross-compound engine—46 and 88 by 60-inch—was shown by test to be 15.28 pounds per indicated horse-power. The engine was operating with steam pressure of 135 pounds at the throttle and 28 inches of vacuum, and developing 1560 horse-power. The steam was 98 per cent. dry. Superheaters were then installed in the plant and another test was made, showing the steam consumption with steam superheated 135 degrees at the throttle. The steam consumption was reduced to 13.25 pounds per indicated horse-power, or 13.33 per cent., the engine developing 1600 horse-power.

The steam consumption of a 75 by 60-inch vertical Southwark engine was 27.25 pounds per indicated horse-power, with saturated steam 98 per cent. dry at the throttle, steam pressure

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135 pounds, and vacuum 4.8 pounds absolute. With steam superheated 98 degrees, the steam consumption was reduced to 23.17 pounds—a saving of 14.97 per cent. The vacuum was 3.5 pounds with superheated steam. It is usual to find that the vacuum is improved where superheat is used in an old plant. Because less steam is passing, the friction through exhaust ports and piping is less, and the steam consumption of the auxiliaries is reduced; not only because of the benefit of superheat in their own cylinders, but because there is less work to be done by the air-pump, circulating pump, feed pump, etc. The saving in steam used by auxiliaries has a great influence on the overall saving of the plant, being several points better than the saving of the prime movers.

The superheaters which served the above, as well as a number of other engines, were installed in Stirling boilers using coal and blast-furnace gas as fuel, and the efficiency of the boilers was improved 3.5 per cent. by installing superheaters, as was shown by boiler tests made before and after the installation.

The modern triple-expansion pumping engine is probably about the most economical of reciprocating engines. The saturated steam consumption of a 29, 54, and 82 by 96-inch—all cylinders and heads jacketed with preheating receivers—was shown by a six-day test to be 10.72 pounds per indicated horsepower, with 150 pounds steam pressure, and vacuum 89 pounds. The steam was superheated in separately fired superheaters and with 95 degrees superheat at the throttle, and the steam consumption was reduced to 9.7 pounds per indicated horse-power—or a saving of 9.5 per cent.; and this was effected on an exceedingly economical type of engine.

The effect of superheat in the case of turbines is more mechanical than thermal, and the benefit comes chiefly from the elimination of moisture, and consequently reduced internal friction. It is evident that, for the same reason, load capacity is increased and the range for peak-loads widened. There is, however, an important economical gain, as shown by a test of a 12,500-kilowatt turbine showing 15.7 pounds steam per kilowatt with dry saturated steam, and 13.75 pounds with 100 degrees superheat—a saving of 12.5 per cent. Another test of a 10,000-kilowatt unit shows a steam consumption of 15.3 to 13.1 pounds per kilowatt,

with 150 degrees superheat at the throttle, which is a saving of 13.7 per cent. The saving to be obtained from superheating the steam to auxiliaries, should be added in order to estimate the improvement in overall station efficiency.

Superheat evidently results in an important improvement in economy, but, as the authors very properly point out, drying and superheating the steam eliminates trouble from leaky joints and danger from water-hammer, broken piston-heads, etc., in the case of reciprocating engines and, even more important in the case of turbines, prevents erosion of the blades. Turbines have had to be entirely rebladed after a few months run, because of the wearing of the blades due to moisture in the steam supplied.

Unfortunately, the time available does not permit a more extended discussion of the many interesting points developed in the paper, and it has been possible only to offer the foregoing notes which it is hoped may be of interest.

Mr. W. N. Flanagan:* I would like to ask if the authors have any comparative data on the heat losses from piping with saturated and with superheated steam, particularly when pipes are covered with modern pipe covering like 85 per cent. magnesia?

Mr. C. A. Brandt: There have been some tests made, but I do not remember the exact figures now, and I would ask for the opportunity to give these later on.

Mr. F. M. Van Deventer:† As the authors of the paper have expressed a desire to bring about a discussion of the subject from a practical standpoint, I want to offer one or two examples of the abuse of superheaters, coming to my notice, and also to enlarge on some of the facts presented.

Lack of thoroughness in providing for the care of superheaters and lack of co-ordination with the boiler and piping lay-out, are probably more common than realized, particularly in small plants where thermometers and gages are usually lacking.

In a moderate size public service station, some new Stirling boilers with Foster superheaters, designed for 100 degrees super-

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heat at rating, had been in service for several months. Thermometer wells had been provided in the superheater outlets, but the pipe covering had been applied so as to hide them. After cutting away the insulation on one boiler and inserting a high reading thermometer, it was found that the superheat ranged from 4 to 12 degrees F., although the boiler was operating at its normal rating. Examination showed that the corrugations of the armor rings on the tubes were completely filled with soot so that the tubes looked and functioned like a pipe with an inch of good magnesia covering. Being questioned, the boiler room foreman stated that although the boiler tubes were blown with a hand lance "regularly every day" he did not believe it necessary to clean the superheaters oftener than once a week. After a good cleaning of tubes, the superheat was observed to range from 90 to 100 degrees and permanent thermometers were then applied to indicate the condition of the superheaters.

In another plant with similar equipment, permanent indicating thermometers had been placed on the superheater outlets and a periodical reading was recorded on the boiler-room log, but no provision had been made to observe the condition of steam at the prime movers. By inserting a mercury well and thermometer at one of the turbines it was learned that 42 degress or nearly 50 per cent. of the superheat at the boilers was lost before reaching the turbine. Investigation, to determine the economical size, showed that the steam header, which was new and covered with a good grade of insulation, was several sizes larger than was warranted. The selection had been made from a published table which set forth the "proper" size of header for a given horse-power served, without any regard to pressure drop, heat loss, cost, or distribution of steam through it. The lay-out embodied a curtain wall with a large header on each side of it, the boiler connections being distributed along one leg, feeders for the prime movers distributed along the other, and the two headers interconnected at frequent intervals—excellent conditions for a minimum size of header without serious pressure drop. The analysis showed that a long section of both main headers was carrying practically no flow, but acting as radiating drums and dissipating the superheat.

Undoubtedly many plants equipped with superheaters are

sacrificing much of the benefit to be derived from them, due to a lack of attention to details similar to those just described.

Although the authors state at the outset of their paper that it is not their purpose to enter into a theoretical discussion of the thermodynamic functions of superheated steam, it seems to me that due cognizance cannot be taken of some of the factors involved in its use, and erroneous impressions are liable to result from their paper, unless the thermal relations involved are presented.

It might be inferred, from the paragraph on condensation loss in pipe-lines, that less heat loss will result from superheated steam in a pipe than from saturated steam under the same conditions; this due to an inert film of steam adjacent to the pipe wall, which renders the resistance to heat flow greater than that of a film of liquid in its place. According to the laws for the flow of heat, the quantity conducted through an element of a given substance is directly proportional* to the temperature difference between the sides of the element; or, to apply the law to the case at hand, the rate of heat loss is directly proportional to the difference in temperature between the pipe material and that of the surrounding air. Incidental to tests by McMillan† it was recorded that in a pipe one-fourth inch thick, covered with one inch of 85 per cent. magnesia, the temperature drops, with saturated steam at 300 degrees F., were: 0.46 degrees through the water film, and 230 degrees through the pipe and covering; and with superheated steam, also at approximately 300 degrees F., the temperature drops were: 4.22 degrees through the steam film and 226 degrees through the pipe and covering. Since the rate of heat flow is proportional to the temperature drop through pipe and covering, the heat loss with superheated steam is $\frac{226}{230} \times 100 = 98.3$ per cent. of the loss with saturated steam. Thus, although the resistance of the dry steam film is nine times as great as that of the water film, this increment is so small compared to the resistance of the

*The coefficient of conductivity varies slightly with the temperature difference, but for the purpose at hand may be considered a constant. Cf. Trans. A. S. M. E. 1918. v. 40, p. 671.

†Trans. A. S. M. E. 1915. v. 37, p. 931.

insulation that the actual loss from superheated steam is only 1.7 per cent. less than that from saturated steam. As most pipe coverings are more than one inch in thickness, a greater proportion of the temperature drop will occur in the covering and less in the inert film of steam or water, than indicated above, so that the slight difference in transmission as just determined will be even less. In view of these facts I believe we are justified, for practical consideration, in concluding that the heat loss from superheated steam is equal to that for saturated steam at the same temperature. But, if we are to compare conditions of the same pressure, the temperature under superheat will be higher than saturation temperature and a greater heat loss will result. For example, in a pipe with two inches of 85 per cent. magnesia covering and 150 pounds gage pressure, saturated, the heat loss to air at 70 degrees F. is 103.5 B.t.u. per square foot per hour, and with 150 degrees superheat at the same pressure the loss is 167 B.t.u. per square foot per hour, or 61 per cent. greater. Actual condensation, of course, will not take place to any considerable extent until sufficient heat has been dissipated to lose all the superheat.

Another factor which should be considered is pressure loss during transmission through a pipe. Superheated steam has a higher specific volume than saturated steam under the same pressure. For example, the specific volume at 150 pounds gage pressure and 150 degrees superheat is $\frac{3.43}{2.82} \times 100 = 22$ per cent. greater than saturated steam at the same pressure. The velocity of flow will then be 22 per cent. greater and the pressure loss increased. This increase seems to be, roughly, eight per cent. for each 50 degrees F. of superheat. In cases where the additional pressure drop is objectionable it can be overcome by larger size of pipe, but the resulting greater cost and greater heat loss by radiation due to the increased surface must be considered.

That the above factors are somewhat cumulative and that the increase in economy due to superheating is not always so great as might be expected, are demonstrated by the following example. Suppose a 1000-horse-power prime mover to be served by a five-inch line 1000 feet long, designed for saturated steam.

Though out of proportion for central station service, this problem is commonplace in steel-mill practice. The principal data are given in the following table:

Item	*Saturated*	*Superheated*
1. Boiler pressure	150 lbs. gage	150 lb. gage
2. Condition of steam	Dry, saturated	150° F. superheat
3. Size of steam line	5 inch	5 inch
4. Insulation—85% magnesia	1.5 inch	1.5 inch
5. Pressure loss	20 lbs.	24 lbs.
6. Pressure at prime mover	130 lbs. gage	126 lbs. gage
7. Radiation loss	174,600 B.t.u. per hr.	276,000 B.t.u. per hr.
8. Condensation	202 lbs. per hr.	0
9. Condition of steam at prime mover	Dry, saturated	125° F. superheat
10. Energy delivered by prime mover	3,412,000 B.t.u. per hr.	3,412,000 B.t.u. per hr.
11. Work per lb. steam—Rankine cycle	316 B.t.u.	338 B.t.u.
12. Assumed potential efficiency	65 per cent.	67 per cent.
13. Work per lb. steam—actual cycle	205 B.t.u.	226 B.t.u.
14. Steam required at prime mover	16,650 lbs. per hr.	15,100 lbs. per hr.
15. Steam required at boiler	16,852 lbs. per hr.	15,100 lbs. per hr.
16. B.t.u. supplied by boiler per lb. steam	1,017	1,098
17. Heat required from boiler	1,715,000 B.t.u. per hr.	1,657,500 B.t.u. per hr.
18. Relative per cent	100.0	96.7
19. Net saving over saturated	0	3.3 per cent.

Notes:

Item 9. All line condensation trapped from steam at prime mover. Radiation loss would have reduced superheat 35 degrees if transmission were effected at constant pressure, but wire-drawing or throttling due to pressure drop aids in sustaining superheat. Net loss as noted—25 degrees.

Item 11. Adiabatic expansion to two inches absolute.

Item 12. In order to allow for the more efficient utilization of available energy by prime mover using superheated steam, potential efficiency is increased three per cent. over that for saturated steam.

Item 16. With feed-water at 210 degrees. No credit is given for increased boiler efficiency. If superheaters are applied to an existing boiler, the fuel economy will certainly be bettered, but in the design of new boilers, whether with or without superheaters, a certain flue temperature is prescribed, as additional heating surface under saturated steam temperature does not pay for itself; hence the use of superheaters will not effect economy by way of reducing the flue-gas temperature.

The economy from superheat is more marked in central station service than in the above example, but that extreme conditions may even reverse the result is shown by assuming an eight-inch line 3000 feet long, with one inch of magnesia covering, to supply 1000 horse-power at the end. An analysis similar to the one presented above shows an actual net loss of 0.7 per cent. with superheated steam. The physical significance of this result is that the line is of such length and condition that all the superheat is lost in transit. Thus, while no actual condensation takes place in the line, the heat loss is greater than with saturated steam because the average temperature within the pipe is higher; the pressure loss is also greater, and, since the prime mover will be served with saturated steam in both cases and lower pressure in the one case, its potential efficiency and steam economy will be less. These factors are cumulative and in favor of saturated steam, as shown by the calculation.

In conclusion, I should point to the fact that while superheating steam usually effects better economy, and should be given serious consideration for all purposes, there are limitations to its use, and each problem should be analyzed and treated according to its particular conditions and merits, taking due account of the steam system as a whole.

Mr. W. N. Flanagan: I would appreciate hearing remarks in regard to desuperheating; for instance, if there is an installation of high-pressure and high-superheat boilers, which it is desired to tie into an existing low-pressure system, through a reducing valve, and where superheat in the low-pressure system is undesirable, or must be kept low. What has been done along this line in reducing the superheat?

Mr. C. A. Brandt: The problem of desuperheating or temperature regulation can be quite easily solved. It can be accomplished in several ways—by passing the steam through a water-cooled tubular receiver; by mixing with saturated steam; or by fine sprays of water. The last method is not recommended, however, as it is difficult to regulate and may prove very detrimental both to the economy and safety of the engine's feed by steam cooled in such manner.

The safest and most efficient way is to use the first mentioned method. The apparatus is called a decalorizer—similar in construction to a condenser. The temperature of the steam can be regulated very closely, and as feed-water can be used for cooling, no loss of heat is suffered.

Mr. W. N. Flanagan: I had in mind turning water sprays into the steam line or into a receiver. In many cases there is either no economical use for hot water, or it is desirable that the heat available from the reduction in superheat shall be used to produce more low-pressure steam. Have you any data on how long it would take for the water to be all evaporated by the superheated steam at any specific fineness of spray and at various steam velocities?

Mr. C. A. Brandt: The amount of water required to reduce the temperature of superheated steam is easily calculated from a knowledge of the total amount of steam to be desuperheated, the steam pressure, the initial and final steam temperature, and the temperature of the cooling water. As stated before, this method is not very good engineering practice, as it will be difficult to regulate the amount of water correctly for the varying steam flows and temperatures, and it is quite likely that great quantities of steam may be condensed at a considerable loss of heat; also, slugs of water may be carried over to the engines and cause trouble.

Mr. W. N. Flanagan: Do you know of any existing installations working on that order?

Mr. C. A. Brandt: I have heard of one case in the Pittsburgh district where water sprays have been used. The use of decalorizers, however, has been successful in many instances, particularly on board ships using turbines with the astern turbine blades on the same shaft as the ahead blading. In land practice there should be very little necessity for desuperheating.

Mr. W. N. Flanagan: The necessity exists where, for high efficiency, a new installation is made with high pressure and high superheat, which, for emergency purposes, must be tied into an

existing low-pressure, low-superheat system within a comparatively short distance—that is, without a long connecting pipe in which the water would have ample time to evaporate. The reducing valve will increase the superheat and thus increase the necessity of its being reduced before delivery into the low-pressure system.

Mr. C. A. Brandt: Yes, such cases, no doubt, will come up, but care should be exercised so that desuperheating is not carried to an extreme. The above mentioned case of using a water spray was at a plant where the superheat at the new boiler plant was only 125 degrees F. The superheated steam line was about 200 feet long, run partly out of doors. At the end of this line, a large water separator was installed, and spray nozzles were introduced to desuperheat the steam for some reciprocating engines located 300 feet from the separator.

The point I wish to bring out is that in this case the transmission line from the boilers to the engines was sufficiently large to reduce the superheat through radiation losses so as to be perfectly safe for any engine in use. Desuperheating in this case cannot be considered good engineering.

Mr. W. N. Flanagan: That is exceedingly interesting, because I had in mind an installation injecting water into a steam line before or after it had passed the reducing valve, and delivering the steam to the engines within a few hundred feet.

There is one other question. Mr. Brandt mentions 125 degrees superheat for existing engine installations. Would this be practicable with no other change in Corliss engines designed for saturated steam?

Mr. C. A. Brandt: There are many Corliss engines now operating very satisfactorily with superheated steam at 125 to 150 degrees superheat, but originally designed for saturated steam. Of course, the Corliss valve is a round plug in a round hole and it is difficult mechanically to get a tight valve, because both the plug and the hole wear out round and cause steam leaks. With piston valves, however, there is no trouble if properly designed.

Most superheated locomotives in this country are equipped with piston valves using superheat of 250 degrees F. with no trouble whatever with lubrication. With slide-valves there are in service many installations using up to 125 degrees superheat with entire satisfaction, and I know of a number of very large triple-expansion engines on board ships, using 200 degrees superheat satisfactorily.

Mr. W. N. Flanagan: I have seen a good deal of trouble with steam of about 75 to 100 degrees superheat with Corliss valves. The steam did not seem to affect other engines at all. The trouble appeared to be that the valves warped with the higher temperatures and scraped at certain points. They wore near the middle and at the ends.

Mr. Grant D. Bradshaw:* As bearing on the points brought up by Mr. Flanagan a few remarks as to my own personal experience with the use of superheated steam may prove of interest. With reasonable degrees of superheat no trouble need be expected in the operation of engines with Corliss valves. They may work a little hard at the outset, but by removing the valve and scraping the high spots to a bearing, no further difficulty should be expected. You speak of Corliss valves binding at the center. This is the point where the usual design provides a reinforcing web across the valve, and expansion of this web makes it necessary to scrape the valve to a bearing when the temperature is materially increased. This difficulty is sometimes experienced with saturated steam as well, and even with saturated steam the seats will be found to have warped at the reinforcing points. I have had experience with one large engine where the exhaust valves broke continually in the high-pressure cylinder. The edges of the valve were abraded, but when we checked up the valves on the Sunday shut-down, a straight-edge indicated that both the seat and the valve were absolutely true. It was only through accident that we found, by checking up the seats right after a breakdown while the cylinder was still hot, that the seats had warped up at the center more than 1/16 inch due to a re-

*President, Andrews-Bradshaw Co., Pittsburgh.

inforcing web at that point. The web was unusually long and extended clear down into the exhaust chest. To correct the trouble, it was necessary to bore out the valve-seat with a specially-made boring bar with glands at each end so that it could be run through while the cylinder was under steam pressure. Thereafter, when the cylinder was cold the seats showed concave but when it was heated up under operating conditions the seats were true. This was on saturated steam.

I have operated one plant, in particular, with 135 pounds pressure and 120 degrees superheat with no operating difficulties whatsoever, although the equipment comprised the greatest variety of engines—Corliss, slide-valve, Porter-Allen, piston-valve, and Buckeye—as well as pumps. The steam lines varied from 50 to 400 feet in length. With the exception of a little warping at first, which was corrected by scraping seats and valves in one or two instances, no trouble was experienced and the plant is in successful operation to-day.

As to the desuperheating, I cannot speak from my own experience though I do know that in this territory there is one plant that is using the system of spraying superheated steam, to reduce from about 250 to 50 degrees. Just what success they have had with it I do not know. In that particular case the spray is being introduced in a large receiver separator. There are several sprays at the top of it, running counter current, I believe, and the water is discharged through traps at the bottom. There is an excess of water used, and still, the steam coming out is at 50 degrees superheat. In other words, there is not an intimate mixture of steam and water. That same condition has to be guarded against rather carefully in putting sprays into a pipeline, because, contrary to the general belief that water and superheated steam cannot exist in the same pipe, my own experience indicates that they can. I have had experience with a steam header in an electric power-plant where water was being carried through along the bottom of the pipe. It was indicated at all the joints and it could be heard in the turbines and yet a mercury thermometer at the top of the pipe indicated fully 100 degrees superheat. That water was introduced on putting a half-dozen boilers giving saturated steam into a tee in the main superheated

steam line. That superheated steam went through a receiver-type separator and still the water was carried over to the turbines with superheated steam.

It is also a pretty hard matter to mix saturated and superheated steam in the same pipe. In one case it was desired to carry the excess steam from a blast-furnace plant a distance of about 1000 feet to a series of mills and a boiler house supplying them, and it was thought that by using a separately fired superheater at the blast-furnaces, superheating to a final temperature around 800 degrees, the excess blast-furnace steam could be carried through this 1000-foot line and mixed with the main quantity of steam, which was probably three times the amount of the superheated steam. In that way, it was sought to obtain a slight degree of superheat, or at least to exaporate the moisture in the mixture. It was tried out and it did not prove a success; in fact, it was necessary to reduce the temperature of the steam from the separately fired superheater to a point where it was possible to operate the engines in case they received only superheated steam. That long line went directly into a tee in the boiler-house header at a point where the header left the boiler house; from there it went to four big mill engines. The first engine got saturated steam; the second engine got saturated steam; the temperature at the third and fourth engines was so high that the soft metal packing in the throttle valves melted and ran out on the floor. Needless to say, the superheat was reduced at once.

Mr. W. N. Flanagan: That is a direct answer to my question. The water would have to be very finely subdivided, as with steam velocities of from 5000 to 8000 feet per minute it would not take very long to carry the moisture from the desuperheater to the engines.

Mr. G. G. Bell:* Referring to the desuperheaters mentioned by Mr. Brandt, it is the custom of evaporator manufacturers to use desuperheated steam. By getting in touch with the Griscom-Russell Company, full details of this company's apparatus can be obtained. This, I think, is of the jet type. The

*West Penn Power Co., Pittsburgh.

arrangement mentioned by Mr. Brandt, in which a surface type of condenser is used, would appear to give very satisfactory results in this case, and in order to save the heat, the condensate should be used as the desuperheating medium, probably after passing through the heater. The reason for using saturated steam in the evaporators is to secure a greater transfer of heat per square foot, and the fact that it is desirable to keep the temperature down as low as possible in order to prevent the formation of scale.

Referring to Mr. Pendleton's and Mr. Brandt's paper, I am very much interested in the statements made regarding the use of cast-iron. While I have had very little experience with cast-iron or semi-steel fittings, I have heard of a great many cases where there was trouble. There are three different possible causes for trouble with cast-iron; first, decrease in the strength of cast-iron as a result of high temperatures; second, unequal expansion as a result of variation of temperature in the cast-iron itself; third, strains induced by the greater expansion in the pipeline. It seems to be more or less the general experience that well seasoned cast-iron will stand up to about 100 degrees superheat, and the impression exists that there is more likely to be trouble with a new line than with an old one. In newer stations designed for temperatures between 600 and 700 degrees, cast-steel valves and fittings are used entirely. In the new Springdale plant of the West Penn Power Company, a non-condensing house turbine is being installed, so that practically all auxiliaries are motor driven. This gets away from the troubles with auxiliaries and greatly decreases the amount of piping. The valves are of the Chapman type having circular or spherical sections, and should be freer from warping or strains than the elliptical section valve. The cost of the steam piping for two 25,000-kilowatt-ampere units, including the cast-steel fittings, is less than one per cent. of the total cost of the power-house. This, of course, would not be true if steam auxiliaries were used. In turbines designed for these high temperatures, steel is used entirely in the high-pressure end. Experience with cast-iron has not been satisfactory; some of the turbines originally built with cast-iron bodies are having these replaced with steel bodies.

Regarding the smaller turbines, considerable trouble was found with 700-degree steam on account of expansion. The solution seems to be to support the turbine shell at the elevation of the shaft, leaving the body free to expand in all directions. Turbine casings, especially at light loads, are subjected to highly superheated steam. This is frequently as high as 100 degrees and may exceed this figure. Such a high temperature change is very difficult to allow for in aligning the turbine when supporting the turbine at the bottom of the casing.

By the installation of a house turbine and motor-driven auxiliaries in a plant of two 25,000-kilovolt-ampere units and six 1500-horse-power boilers, 19 small steam turbines and 14 reduction gears were eliminated.

The authors show about one per cent. gain for every 12 degrees of superheat. Mr. Snyder shows in his discussion that only about 40 per cent. of this was to be expected from the increased thermal efficiency; however, the effect of superheat on the turbine is to reduce greatly the friction of the passage of steam through the blading, and the remaining 60 per cent. of the saving is effected by this means. In turbines using 200 to 250 degrees superheat, at full loads the superheat does not extend past the point at which the steam is about atmospheric pressure. If it is desired to extend the superheat through to the exhaust chamber of the turbine, it would be necessary to resuperheat the steam at this point another 200 degrees. The effect of this additional surperheat would be a gain in economy of about the same amount as when superheating the high-pressure steam; that is, one per cent. for every 12 degrees. This has not been worked out satisfactorily from a financial standpoint, but is one of the main openings in the future for the separately fired superheater.

One of the main advantages of superheating steam in a power-plant is to decrease the maintenance on the turbines. The turbines using saturated steam are subject to erosion of the casing and blades. We have lately had two 6000-kilowatt machines rebladed and the cylinder surfaces refinished, so as to reduce clearance, at a cost of about 40 per cent. of the original cost of the turbine installed in 1912. This was after seven years' use. This erosion was worse at the high-pressure end. It is probable

that if superheated steam had been used, this reblading would not have been necessary.

When installing superheaters in old plants, it is very important to consider the space available, as the old boilers are usually set very close together. In some types of boilers there is very little space between the top of the tubes and the drum; and it is a mistake to crowd in additional apparatus which will prevent proper maintenance of the boiler and baffles, as well as the superheater to be installed.

With regard to lubrication of turbines, when the seal at the high-pressure end is in close proximity to the bearing without proper means of cooling the shaft or preventing the steam from escaping from the gland directly into the bearing, the oil is apt to be affected. For this reason we would favor the use of a water-seal or of a considerable space between the glands and the bearings.

One of the main troubles with superheaters in large boilers having furnaces of approximately 25 feet inside width results from the heating and cooling effect that takes place when fires are cleaned. The production of steam at such a time is greatly reduced. After the fire is cleaned, the air is turned on and the furnace temperature increases rapidly. The temperature of the gases rises correspondingly and overheats the superheater while the flow of steam through it is small, especially at the middle on account of possible short circuiting of the steam. The boiler begins to generate its normal amount of steam, the column of water rises and it is not an uncommon thing for water to be carried over into the superheater along with the steam. These sudden changes in temperature cause bending and deformation, which may be sufficient to rupture the connection between the superheater header and tubes.

It is more difficult to support the superheater properly when it is inclined or vertical than when it is placed horizontally in the boiler. Particular care in designing is necessary to support the superheater properly and to distribute the steam so that there are no idle places at times of light load.

In places where deflection in the superheater header occurs, the trouble is apt to be communicated to the external piping. We

have found it necessary to use two 90-degree elbows so placed in the boiler piping as to get a slight rotation on the face of the flanges. This has enabled us to keep the piping tight on large boilers in which we found it practically impossible to do so with the original design of connections.

In the paper, the amount of area of turbine blades exposed to the steam is cited as objectionable on account of the condensation. If the turbine is well protected with a heat insulating medium, the loss in condensation is not so objectionable as the loss in friction. The action of steam in a turbine is similar to that in a uniflow engine; that is, the walls of the turbine remain at nearly a uniform temperature, so that, after once heating up the walls, there will be very little condensation. The case is different in the ordinary steam-engine, where practically the entire length of the cylinder is exposed to maximum and minimum temperatures, there being a change in temperature for every cycle of the engine.

With regard to the gain to be made by a superheater, this depends on the rating at which the boiler is run; for instance, on the Springdale boilers at the various per cent. ratings we are guaranteed the following:

Per cent. rating	Degrees
100	125
200	183
300	217
400	232

In addition, with boilers of the same design, there is a very marked difference in the degree of superheat obtainable with different brands of coal. Coal having a low ash content and fusing at a high temperature, and which can be burned to give 14 per cent CO_2 will give a comparatively low superheat, and an increase in the feed-water temperature in an economizer, if the boiler is equipped with one; whereas, coal with high ash, and fusing at a low temperature, which will under ordinary circumstances produce around 10 per cent. CO_2, will give a very high relative superheat and rise in feed-water temperature in the economizer —the relation being, roughly, inversely as the amount of CO_2.

This matter should be recognized when considering an investment in superheaters and economizers.

An interesting item with regard to the action of traps, brought to my attention by Mr. Bradshaw, is that the ordinary bucket trap will not work successfully with superheated steam, after it has once started to leak; provided that the steam leak is greater than the rate at which the superheated steam can be desuperheated by condensation. The superheated steam will gradually evaporate the water, allowing the bucket to lower as if it were filled with condensation, and it will stand open until the trap is filled with a slug of water or filled from an outside source. This, of course, would be very expensive, and would go a long way to offset the advantages of superheated steam.

In conclusion, the gain in economy, while substantial, is not the only thing to be taken into consideration when buying superheaters. The effect on the maintenance of steam-turbines is very beneficial. In a plant designed with electrical auxiliaries and a house turbine—which in itself will show an improvement in station economy of about two per cent.—the additional cost of buying extra heavy piping with cast-steel fittings is a very small percentage of the plant cost. In addition, this type of station will have a very low auxiliary maintenance, and will make a much simpler and better station from an operating standpoint.

Mr. Grant D. Bradshaw: I believe Mr. Bell misunderstood what I said about it being a tilting trap. What I referred to was a bucket-type trap where the bucket floats on the surface of the water in the trap. I have had actual experience with that type of trap in superheated steam where it was necessary to fill the trap with water several times a week to keep it from remaining wide open. It was not due to slight leakage and it was not due to evaporation from using a short connection between the trap and the steam line. The water disappeared from around the bucket inside the trap, exactly as if the bucket were submerged on being filled with water, therefore the trap remained open.

Mr. W. P. Chandler:* In some cases of excessive priming in a boiler, water will be carried through the superheaters and into the steam mains. In one case where this happened, deposits of soluble salts were found in the mains, in the traps, and on the blades of a turbine supplied by this main. However, at no time did the temperature in the steam-chest of the turbine fall below 100 degrees superheat. It would appear as though the moisture existed as a mixture with the superheated steam and was not evaporated at the expense of the superheat.

A desuperheater was installed in connection with a superheated steam boiler house to make available for use certain excess steam generated in a saturated steam system. The desuperheater consisted of a large steam separator equipped with spray nozzles for introducing water at the top and with traps attached at the bottom for any water not evaporated. In operation it was found that twice as much water was required to reduce the superheat to less than 25 degrees which was shown by the thermal change of the steam itself, the traps removing this excess amount.

Mr. W. N. Flanagan: I have found a white deposit on turbine blades running at 200 degrees superheat. The deposit must have been contained in water that passed right through the superheater from the boiler.

Mr. Max Hecht:† The question of the deposit carried in the steam has been followed by us for several years. In our largest plant we have 56 boilers of 37,700 horse-power capacity, of which all but 7500 horse-power are equipped with superheaters. During the peak, all of the boilers are forced to carry at least 200 per cent. of their rating.

The water-supply is made up of approximately 90 per cent. condensed steam from surface condensers, and 10 per cent. make-up water from a lime and soda-ash intermittent water purification plant. The make-up water carries two grains per gallon hydrate alkalinity and two grains per gallon carbonate alkalinity

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and holds very closely to this limit. When mixed with the condensate, however, the water fed to the boilers is almost neutral to methyl orange and phenolphthalein indicators.

On our various turbines, and on the steam side of condenser tubes we are finding a film deposit, insoluble in water. A sample of the deposit scraped from the blading of a turbine analyzed as follows:

Water soluble SO_4	trace
Water insoluble silica	0.74%
Magnetic oxid of iron	61.96%
Copper	12.50%
Calcium	trace
Magnesium	trace
Oil	13.01%
Moisture and volatile organic matter	11.79%
	100.00%

It is evident that the amount of soluble salts carried over in the steam and held in the deposit is negligible. The copper content should not be considered, as it is an accidental inclusion in the sample, due to scraping of the blades with a steel tool. The iron content is attributed to the erosive action of superheated steam on the pipe-lines, fittings, and steel parts of turbines; and, since the steam is circulated in a closed system, the iron content is not eliminated. The oil finds its way into the system via reciprocating auxiliaries exhausting to the heaters. Although the amount is exceedingly small, it accumulates and acts as a binder for the solid matter carried in the steam.

When large amounts of soluble salts are found in pipe-lines, turbines and engines, and where boilers are equipped with superheaters, it is evident that slugs of water are carried through the superheaters.

The boiler feed supply must be free from suspended matter, and must carry a minimum of salts, and no oil must be present in the boilers.

Superheated steam generated under such conditions will carry a minimum of entrained solid matter.

Mr. W. P. Chandler: In the case I mentioned, 80 per cent. of the material deposited was soluble sulphates or carbonates; the only insoluble material being calcium carbonate and about three per cent. of silica, with a trace of iron and aluminum oxids.

Mr. Max Hecht: Was that a jet condenser or a surface condensing plant?

Mr. W. P. Chandler: A jet condensing plant.

Mr. W. N. Flanagan: In the case of which I spoke, we found quite a percentage of soda-ash in the deposit on the turbine blades. The deposit was fairly white. The water softening equipment was of the continuous type and much overloaded so that the water was probably only imperfectly treated; in some cases receiving excessive treatment, and in others an insufficiency.

Mr. D. D. Pendleton: I would like to have Mr. Brandt give you some fuller details than I can give, but I want to emphasize the fact that all these cases are very interesting. I believe it is a question of studying each individual case, the feed-water treating, the type of superheater and the various other details. Water cannot go through the superheater to any great extent. If it does, it must be due to defective design. I believe Mr. Brandt can bring these points out much more clearly.

Mr. C. A. Brandt: As a preface to my discussion, I wish to express Mr. Pendleton's and my own appreciation of the kind attention which you have given to the paper presented this evening, and I can assure you that it has been a pleasure for us to be here to discuss this very important subject. The question of coal conservation is one of the most important problems before the country to-day, and I believe it is conceded that the use of superheated steam is a factor which produces a greater economy in steam and fuel, for its cost, than any other economy-producing device installed in power-plants.

I wish also to congratulate the Engineers' Society of Western Pennsylvania on the very excellent discussion of the paper that has been presented this evening. There have been a great many

questions brought up which will take considerable time to answer, and which I will endeavor to handle as far as the time permits.

Mr. Snyder's excellent discussion is very interesting, and a discussion by a man of such wide and varied experience is worthy of careful consideration. There are a few points that could be discussed further; for instance, the application of superheaters to power-plants now operating with saturated steam. The tremendous increase in the cost of material and labor during the last few years will make it more difficult for the industrial concerns of this country to scrap existing power-plants and replace them with new ones. Only a few years ago there was a general feeling that it would not pay to modernize existing plants, and that the best thing to do was to build a new plant, equipped with all modern appliances.

This attitude has been completely modified, as the cost of replacement to-day is so much greater than in the past that it is difficult to obtain the necessary capital. It seems, therefore, to be the part of good judgment for an industrial organization to study its existing power-plants and find out whether, by the application of some coal- and labor-saving devices, they cannot be brought into a comparatively high state of efficiency. We all agree that the large modern steam-turbines have shown great increases in efficiency, but I am unable to see how the efficiency of boilers can, or will, be increased by making them in very much larger sizes than now prevail. I believe it will also be conceded by every engineer who is well informed on these matters, that it is quite possible to build a steam power-plant of very small dimensions that will be just as economical as far as the thermal efficiency is concerned, if the high pressures, superheats, and vacuums are utilized in these smaller plants, the same as in the large ones; and it seems quite possible that it will be easier to obtain these high pressures and superheats with the small equipment than with the larger.

What I have particular reference to is the application of superheat in existing power-plants, and I agree with Mr. Snyder that superheat in such plants should be considered carefully. I am positively convinced, however, that there are very few steam power-plants, no matter how old, that cannot be operated and

maintained satisfactorily using superheat of 150 degrees. The only objections that have been brought out are the possible failures of cast-iron fittings, and the lubrication of reciprocating engines.

The fact has been brought out in the paper that there are to-day over 37,000 locomotives in operation in this country, and 25,000 locomotives in foreign countries, with collector castings, steam-pipes, steam-chests, and cylinders of cast-iron, operating with 250 degrees superheat, and even more, with positively no failures attributable to the high steam temperatures. When it is also considered that this equipment is subjected to most severe temperature fluctuations, this certainly should be ample proof that a good grade of cast-iron is entirely satisfactory for the use of superheated steam up to 650 degrees.

These facts, together with the fact that there are many power-plants in operation to-day with cast-iron, having superheats up to 125 and 150 degrees, should be sufficient evidence that there is very little to this cry that cast-iron is unsatisfactory for superheated steam. The trouble that possibly has existed at times is unquestionably due to poor erection of the piping where the lineal expansion was not taken into consideration.

With reference to the lubrication, it may be set down as a positive fact that if the proper grade of oil is used in valves and cylinders, metallic packing used on the rods, and the lubrication properly applied by either hydrostatic or force-feed lubricator, there should be no trouble whatsoever with the lubrication of any reciprocating engine if proper precautions are taken. There are to-day in operation, and successfully lubricated, a great many thousand engines under most adverse conditions, with piston-valves using 250 degrees superheat; and there are a great many Corliss engines operating successfully with as high as 150 degrees superheat, and slide-valve engines with 125 to 150 degrees.

Mr. Snyder's remarks relative to the internal cleaning of superheater units deserves some further discussion. It is felt that if the superheater is properly designed so as to maintain satisfactory steam velocities throughout the units, and that the design is made so as not to permit an increase in the steam area through each individual unit so as to cause a sudden reduction in the steam

velocity, there will be no danger of any collection of scale in the units. There are several makes of stationary superheaters where each unit consists of a U-tube with an internal steam core through the straight portion of the unit—as it is manifestly impractical to put these cores through the bends. This condition produces a sudden enlargement of the internal steam area at the bend, and a reduction in the steam velocity to one-third or one-quarter of that through the other parts of the unit. This condition actually produces a pocket where any scale-forming material that is carried through will collect, and as these bends without cores are usually exposed to the hottest action of the gases, such accumulation may cause the burning out of the unit.

An essential requirement of superheater construction is, therefore, to maintain uniform steam areas, and it may be of interest to mention right here that the locomotive superheaters made by the Locomotive Superheater Company, with this principle carefully watched, have been in operation for ten and eleven years on roads having the worst kind of boiler feed-water, without the slightest formation of scale on the inside of the superheater. The writer has personally examined thousands of units that have been in such operation, and found them as clean as a whistle on the inside; and it stands to reason that this condition must prevail, or the units, the ends of which are exposed to temperatures as high as 1800 to 2200 degrees, would burn out very rapidly.

Mr. Snyder suggested in his discussion that it would be of great value to engineers to have figures giving actual results obtained from comparative tests of plants with superheated and saturated steam. Such information was not given in the paper because so many tests have been made and so many results published that it was thought unnecessary to burden this paper with such testimony. Comparative results obtained by the use of superheat on locomotives have been published by Dr. Goss, then at Purdue University, and the Pennsylvania Railroad has also published a dozen or more bulletins of complete locomotive tests proving the statements made in the paper. In the marine and stationary fields, records are available, also. Mr. Primrose, in his valuable contribution has given several instances where comparative tests have been made. In the cases mentioned

by Mr. Primrose, however, comparatively low superheats were used. Better results and greater saving can be obtained for certain types of prime movers with a superheat of 150 to 200 degrees, or more, and a reduction in steam consumption of as much as 20 to 25 per cent. is possible.

As pointed out by Mr. Primrose, the effect of reduced steam consumption on the condenser vacuum and the efficiency of the auxiliaries is of considerable importance for some plants, especially the auxiliaries of the condenser, such as the pumps.

Mr. Bell has raised a point which, although not touched upon in our paper, comes within the scope of our subject; that is, the intermediate superheater. For instance, in a 10-stage turbine, if the initial superheat is 200 degrees, the superheat will disappear at the fourth stage, and additional economy could be obtained by having the steam superheated again. This was considered as impracticable from a financial standpoint, as it was thought that an additional separately fired superheater would require a special furnace and fireman; also special attention, and, on account of the comparatively large dimensions of the low stages, any excess of superheat would be injurious.

Recently, a number of separately fired superheaters, operated with oil, have been installed and these require very little attention. The automatic thermostatic control has also been so far developed that an automatic regulation of the steam temperature is assured, so there is nothing to prevent the application of the intermediate superheaters and it is to be expected that this arrangement will be considered in the future.

With reference to the sudden changes in temperature, which take place when fires are cleaned, a properly designed superheater is so arranged as to take care of the expansion and contraction, so that no deformation of the superheater unit will occur. In this respect, a unit consisting of several loops, is more suitable than a single U-unit. A clamp and bolt joint between units and headers is better able to withstand the strains due to expansion and contraction of the units, than is an expanded joint.

As pointed out in the paper, by locating the inlet and outlet of the superheater at opposite ends, a uniform distribution of the steam through all units is secured. The point made by Mr. Bell—

that the degree of superheat obtained, with the same type of boiler and the same rating, depends upon the coal used as well as upon the type of stoker—is well taken.

Regarding the operation of traps in lines carrying superheated steam, it can be said that, if a flow of superheated steam is secured, no traps are necessary and where they are installed it is good practice to have them connected to the line only when starting, before the line is all warmed up. When the normal condition is attained, and superheated steam flows through the line, the traps should be shut off.

Mr. Bradshaw's remarks are very interesting. They illustrate the point that it is quite easy to take care of any slight difficulty that might arise as regards proper operation of Corliss, piston-, or slide-valves, when operated with superheated steam.

Another point which was brought up, I wish to discuss a little further; namely, the possibility of water being carried over from the boiler through the superheater, in case the boiler has a tendency to foam. In designing a superheater, such items must be taken into consideration, and, where conditions of this kind are likely to prevail, the superheater should be designed to take care of them. It is impossible, of course, to design a superheater to produce certain degrees of superheat from steam that is dry, or with a specified amount of moisture, and then expect that it will deliver the same degree of superheat when large quantities of water are carried over; but it is quite possible to design a superheater so that, where bad water conditions exist, any slugs of water that may be carried over will be broken up and the water evaporated.

With some makes of superheaters, the individual units are of large diameter and with only one easy loop. With such superheaters, any water carried out will not come in contact with the heating surface, but will go through the superheater without being evaporated. To take care of conditions of this kind, it will be necessary to design the individual units with a number of bends and returns, in order definitely to break up the stream of moisture in the steam, and thoroughly mix the wet core.

The locomotive superheater is a very effective example of how this is accomplished. A locomotive receives its water from

a great many different sources of supply—good, bad and indifferent—and the method by which such waters are treated, in the few places where treating apparatus exists, certainly cannot be as nearly uniform as the treatment possible at the central stations. The water conditions for locomotives can, therefore, fairly be said to be worse than in any stationary power-plant. Furthermore, the possibility of foaming, and of moisture being carried over into the superheater, is very much greater; because the steam-pipe opening, or throttle pipe is located only 18 to 24 inches above the surging water level—usually immediately above the front end of the fire-box, where the greatest evaporation occurs. Examination will also indicate that the steam liberating surface in a locomotive boiler is not greater than that of a stationary boiler, considering the amount of steam generated. Even under these adverse conditions, the modern locomotive superheater is so designed that it will not only evaporate the excess amounts of water and moisture that are carried over, but will also deliver superheats up to 250 degrees.

Several of the gentlemen who have just spoken have referred to the necessity of keeping the superheater units free from soot and ashes, and Mr. Van Deventer mentioned a case which very frequently occurs, where a superheater was found clogged up with soot. This feature should, of course, be given most careful consideration, as there is certainly no use in spending money on apparatus which will fail to perform its duties.

Mr. Van Deventer figures out from the test by McMillan that the resistance to heat transfer, or the temperature drop from superheated steam to the outer wall of the pipe, is about nine times as great as that in the case of saturated steam and, when the pipe is well insulated, the loss through radiation with superheated steam is about 98 per cent. of the loss with saturated steam on account of the high resistance through the insulation; but most of the existing power-plants are not in such an excellent condition and very often some flanges, fittings, and valves are not insulated and the radiation at these points depends only upon the difference in temperature between the metal and the air, and this is where the greater resistance to heat transfer with superheated steam is of great importance.

The statement that with superheated steam the pressure drop increases, is not quite correct. It is quite true that for the same weight of steam the volume of superheated steam is greater, resulting in an increased velocity for the same pipe size. However, the drop in pressure depends not only upon the velocity, but also upon the density of the steam, which is less for superheated steam. Furthermore, on account of the smaller steam consumption, a smaller amount or weight of steam flows through the superheater for the same horse-power, which also decreases the velocity. Moreover, even with the same amount of steam, the pressure drop is less with superheated than with saturated steam. With saturated steam, any loss of heat causes condensation, and the pipe walls become wet, so that the steam more readily adheres to the walls, thereby causing more friction.

It is, no doubt, commonly known that with superheated steam a greater velocity in the piping can be allowed than with saturated steam, and that velocities up to 10,000 feet a minute are very often used. The greater velocity requires a smaller pipe, and in that way a considerable reduction in radiation losses is accomplished. We know of cases where in a power-plant, by converting an engine from saturated to superheated steam, an old eight-inch pipe-line was replaced by a new line five inches in diameter, and the pressure drop through the superheater and a 200-foot pipe-line was only about eight pounds.

The data given in the table—showing a theoretical saving of 3.3 per cent. from 150 degrees of superheat—are the results of theoretical consideration, only. In reality—and this is what interests us most—if the prime mover is a reciprocating engine, considerable saving is accomplished by the elimination of the condensation. Moreover, this elimination is not to be compared with that of the piping, no matter whether the engine is insulated or not. With the initial saturated steam coming in contact with the cylinder walls and steam ports which were just swept by exhaust steam, and are, therefore, comparatively cool and wet, condensation occurs because the steam gives up, without much resistance, a part of its heat; while, with superheated steam, on account of its higher resistance to heat exchange, these losses are considerably reduced. If the prime mover is a steam-turbine, considerable

saving over saturated steam is usually experienced by reduction of the blade friction. That this is the case, is clearly proven by the fact that the blading of the turbine working with saturated steam is very quickly worn out, and there must be some friction, with a corresponding loss in power, which causes this wear.

MILITARY SEARCHLIGHTS

By Lieut. S. G. Hibben*

There is scarcely any other example of the rapid progress of development resulting from intensively applied science, equal to that of the arc searchlight. What was actually done under stress of war conditions cannot be fully realized from this brief discussion of the subject, unless one has noted the status of military searchlights in, say, 1915 and compared this with the condition of the units as we see them to-day. Searchlights experienced undreamed of modification, and the engineering activities connected with them during the past three years more than counterbalanced the relative inactivity of the preceding 15 years.

Previous to the outbreak of the last war and before aerial combat or transportation became established facts, there were, it is true, no particular incentives towards the design or manufacture of the mobile or field models of searchlights; even though, for coast defense uses, we did have some fairly good projectors in service. Their construction prevented an elevation of the beam of light much above the horizontal, and for this and other reasons, they left our coasts and frontiers unprotected against night aerial warfare.

As for searchlights in the Navy, these have developed in step with the field units, but their problems have been those of arc mechanism and control, and not of portability. That story is too long to include in this discussion.

Even under the shadow of European war we had no funds nor any considerable organization for the development of military searchlights, and, though developments came rapidly when we really did realize the need of it, and when the General Engineer Depot took hold of the work with characteristic determination, yet, to be perfectly frank, this country was never able to put into France the best or, one may even say, the practical types of its searchlights. The greatest regret is that these developments could

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not have been made sooner, and it is our earnest hope that they will not again become dormant.

The writer had much to do with the design and building of searchlight apparatus in this country, and later went overseas with a searchlight battalion. The experiences at the front brought out vividly what features should and must be a part of such apparatus and the first thing learned was that our searchlights—the mobile anti-aircraft types of 1916–1917—thought to be the very best we could produce at that time, were absolutely unserviceable in France.

Up to the end of the year 1916 there were in service a few good coast-defense lights, mostly equipped with 60-inch glass mirrors and using what is known as the low-intensity arc (large diameter carbons), but all were of the heavy base types that required concrete emplacements or wheeled trucks for their limited range of movement. (See Fig. 1–2.) For field service their weight was well-nigh prohibitive, yet when mounted on heavy low-wheeled trucks they could be transported where macadam highways or railroads existed, and lacking more flexible models such units were shipped overseas and employed around a few cities and ammunition dumps against hostile aircraft. Aside from weight, they were ill adapted to anti-aircraft defense, for they were limited to an elevation range of 30 degrees and their control was sluggish.

French and British portable models were available at this period, and were greatly in the majority among the Allies on the Western front.

At this time, it was well known that the Germans were using mobile field searchlights but, although the approximate size and type were known, no definite details of such units were available in this country until 1917, when a German outfit was captured intact and reported in detail to Washington. About this time, also, it became fairly certain that night raiding by Zeppelins and taubes was, next to the submarine warfare, the most to be feared of all the procedures that were destructive to military morale. Equally obvious was the fact that this nation had not a single mobile anti-aircraft searchlight.

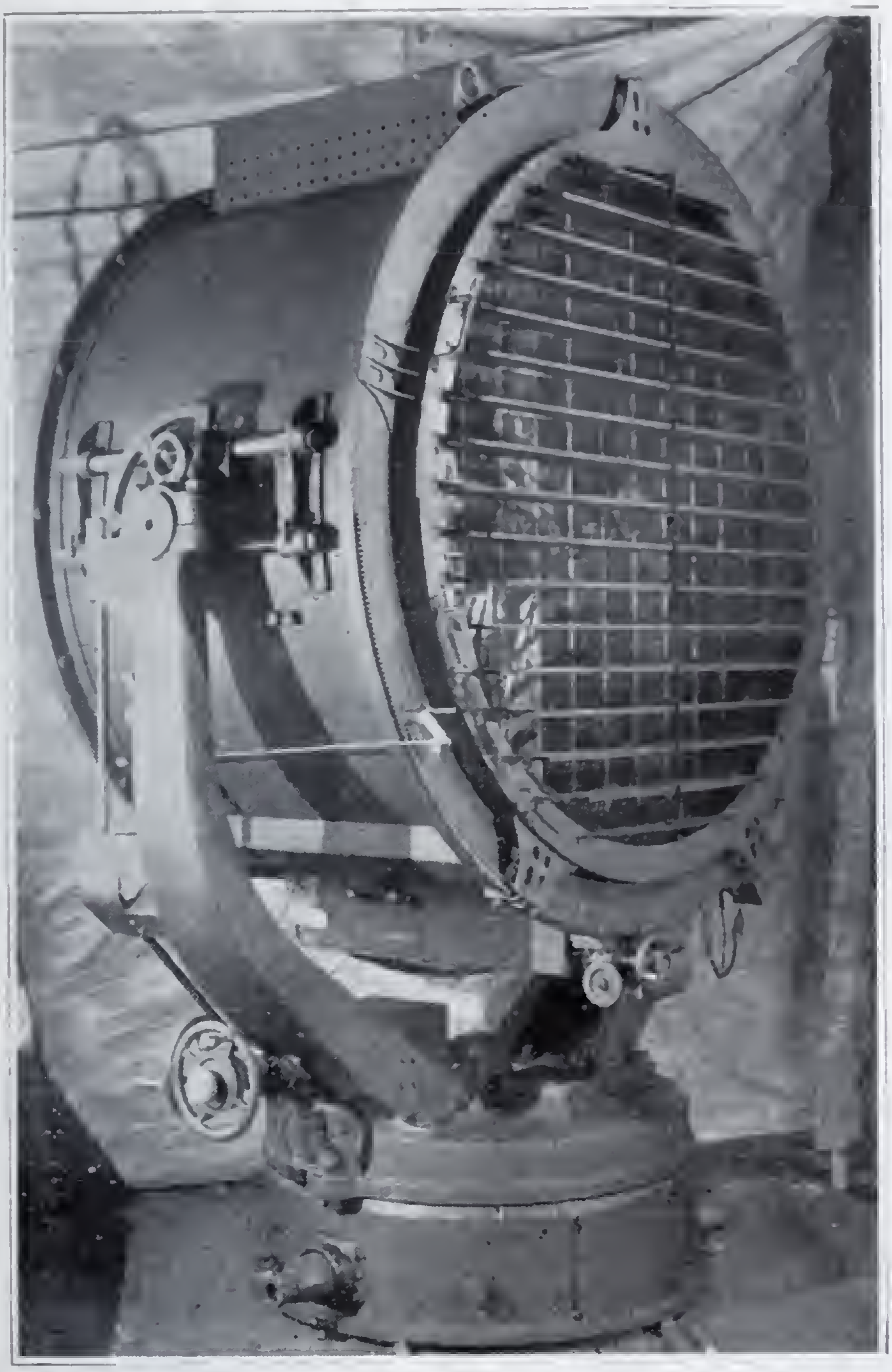

Fig. 1. A 1914 Model Heavy-Base 60-inch Searchlight.

The result was that the general style of the captured German light was speedily copied, adding our recently developed high-intensity arc mechanism, and giving us several units that were known as the "limber-caisson" types. These were of the 24-inch size, later proving too small for anti-aircraft operations. The first ones went to France in the fall of 1917. Fig. 3 illustrates the unit of this type.

Their faults were many. It is interesting to consider this first American mobile searchlight for it was the means of discovering how to avoid many mistakes that will be interesting to any engineer.

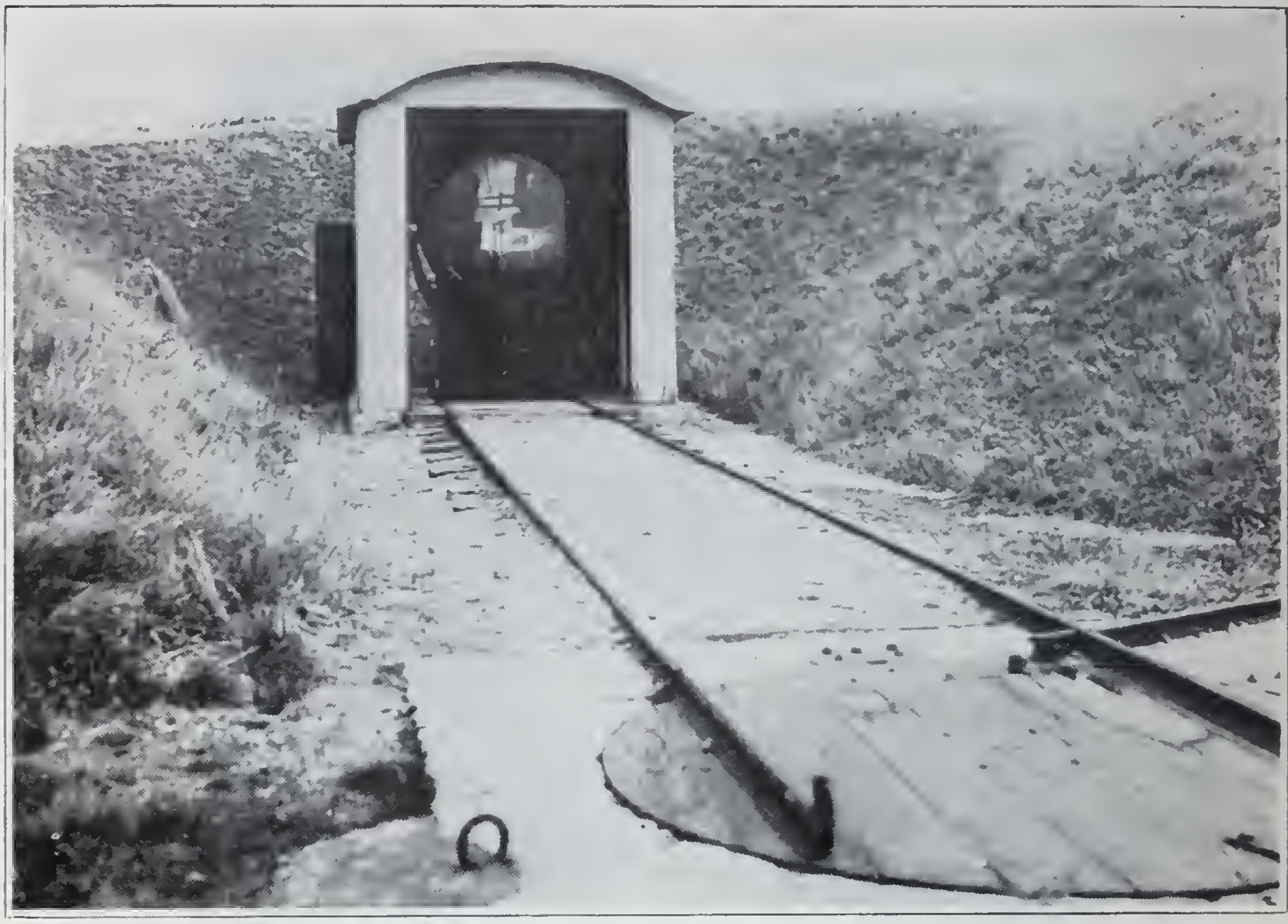

Fig. 2. Concrete Shelter and Emplacement for a 60-inch Coast Defense Searchlight.

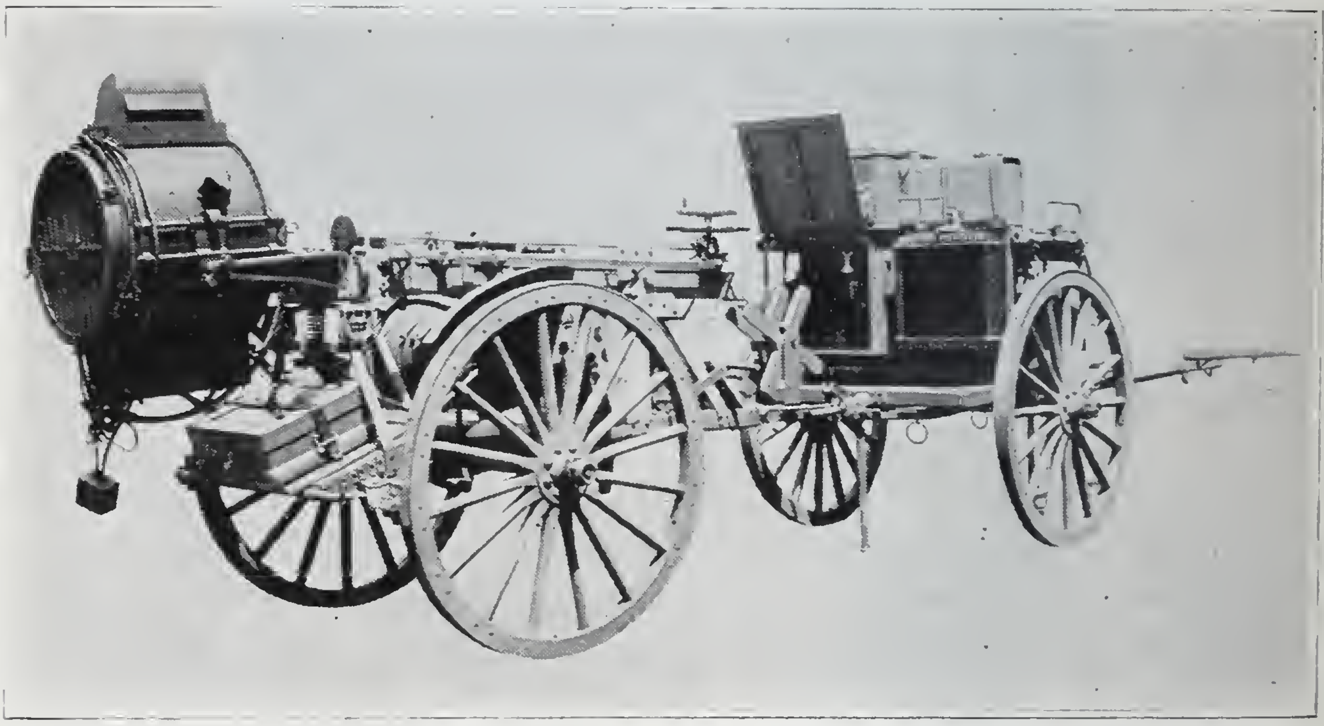

Fig. 3. Limber-Caisson Searchlight, 24-Inch Model of 1917.

A few features that contributed to their unpopularity were as follows:

They were horse-drawn, and horses are passing out of modern warfare.

Sufficient protection against rust was lacking.

They were of too many parts (174 items carried as spares).

Removable parts were not all anchored, and became lost easily.

A minimum crew of five men was required to operate each unit.

They were of elevating mast design—useless for their particular service.

The engines—five-kilowatt gas-engine sets—were uncertain of functioning in cold weather.

Units were too noisy.

They were in no manner fool-proof.

Their training—altitude and azimuth movements—was not sufficiently fine.

The beam was not intense enough to range on high and swift air-craft.

Following this first field searchlight came one of the most interesting types, which formed the basic model of the improved units that we have to-day. This second outfit consisted of a heavy truck, upon which was carried a Ford chassis which mounted the searchlight itself, and which rolled down a pair of sloping skids from the tail gate when the unit was to be operated. Fig. 4 shows this unit going into operation.

The most striking feature was the mounting of a 15-kilowatt generator placed in front of the truck gas-engine and directly connected thereto. An unbreakable switchboard was provided, having radium luminous instrument dials and handles, etc., and a large reel of electric cable was provided so that the truck itself (the power unit) could be dug in or concealed some two hundred yards from the searchlight proper.

Salient features of the searchlight were: Its size was larger than preceding types, viz: 36-inch mirror; it was of automatic control, and had forced ventilation; the carriage was hand drawn and could be easily concealed; two or, at the most, three men could operate the unit; upon reaching any position the outfit could go into operation immediately, or could operate while moving across country; the entire unit was self propelled, and on good roads could maintain a speed of 12 miles an hour.

Fig. 4. The 36-Inch Heavy Truck Mobile Light Model of 1916.

The one great and deciding factor that soon made it evident that this mobile unit was unsatisfactory was its weight. Transportation conditions are terrible in any war, and on the Western front, it became positively impossible to rely upon getting these heavy 5½-ton trucks to the front during winter weather. This model, nevertheless, was a long step forward, and from it grew the present designs that will be our masterpieces until some years in the future. One hundred and eighty of these outfits were built, of which about thirty reached France.

Hastening over some intermediate steps, it is sufficient to note that late in the fall of 1918 the light-weight 1½-ton commercial trucks (such as the Cadillac and the Dodge) replaced the former 5½-ton trucks; that on these the generator (20-kilowatt, 150-volt) was mounted midway of the main chassis, and that the searchlight itself underwent a complete change from the enclosed or barrel shape to the open or "dish-pan" style. These searchlights were 60-inch, were operated by a crew of five men, weighed complete (including truck) 9000 pounds, and cost about $9000 each. No other development has been so radical as this. About ninety such units were authorized, one of which reached the rear of the second Army in France in October. A comparison between Fig. 5, the 60-inch heavy base model of 1917, and Fig. 6, the 1918

Fig. 5. The 1917 Model, 60-Inch Barrel-Type Searchlight and Power-Plant.

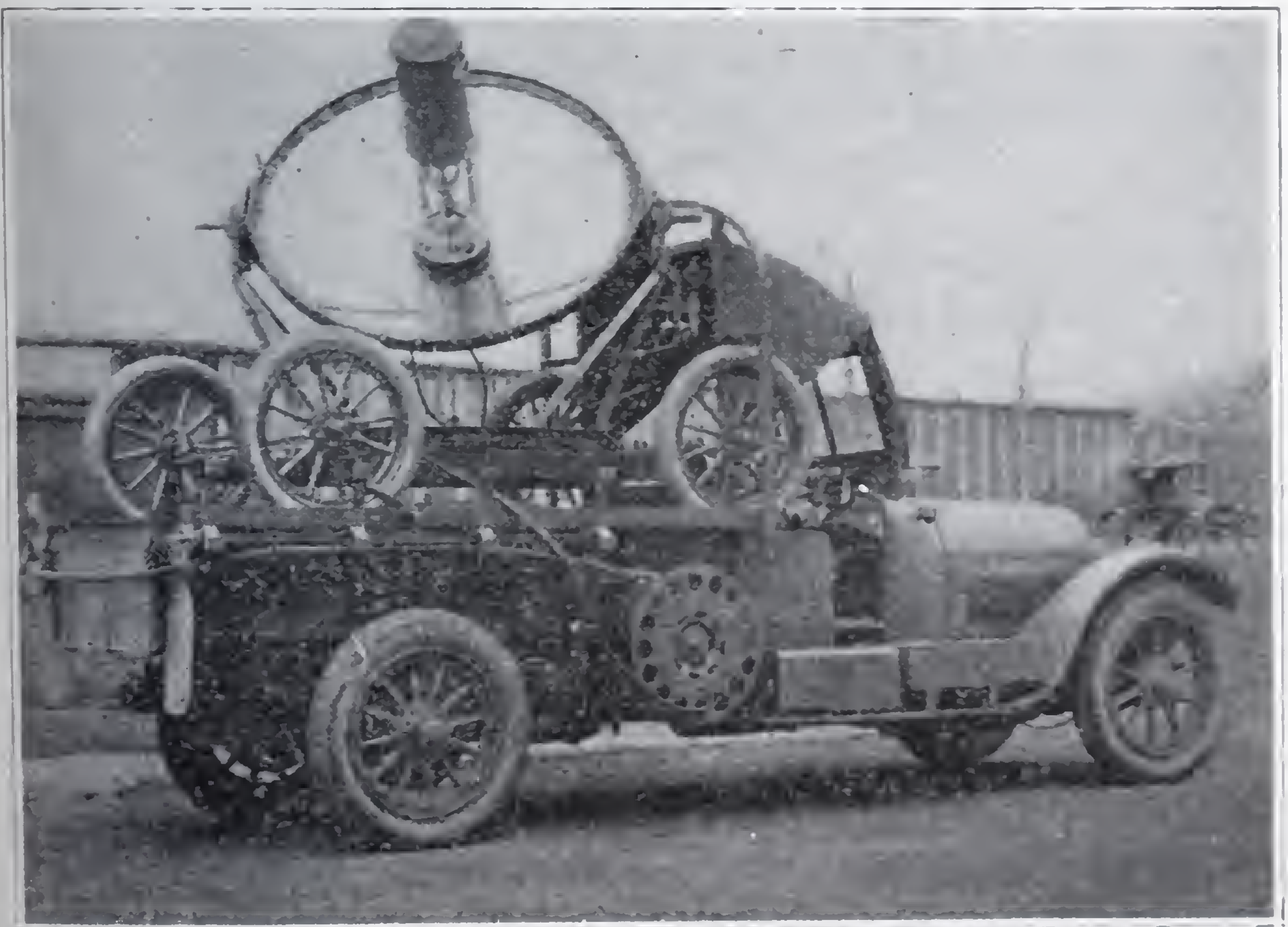

Fig. 6. The 1918 Model, 60-Inch Dish-Pan Type Mobile Searchlight.

"dish-pan" model, shows how great was the elimination of weight and bulk.

The mirror in the latest models is completely exposed, having no enclosing housing, no plate-glass front door, no iris, nor venetian shutters. The high-intensity arc mechanism is supported out in front of the focal point of the mirror by rods from a hole in the center of the mirror, in what the enlisted soldier called a "tin can."

The size was increased from 36-inch to 60-inch mirror diameter. These latest designs involved a 60-inch searchlight weighing only one-tenth as much as the 60-inch unit heretofore considered standard. They cost only one-third as much as the preceding models, are from 10 to 15 per cent. more powerful (less beam divergence, no loss from front glass doors, and better arc operation), and consist of only about one hundred parts as against several thousand parts of the old design. They are much more rugged, and can be produced in one-fourth the time required for producing the old model.

In all of these developments, the most interesting feature has been the problem of the reflecting mirror. This constitutes a large proportion of the weight of the searchlight and is, next to the arc, its most important part. In all the large models the light source is the positive arc crater, placed at the focal point of the mirror, and the beam is entirely of reflected, almost parallel rays. Perhaps 70 per cent. of the generated light falls on the mirror (See Fig. 7) and should be reflected with a loss of not more than 15 per cent. No direct light from the arc enters the beam—the mirror is directly responsible for the shape and homogeneity of the beam, hence for the efficiency of the searchlight. Silvered glass paraboloids were used almost entirely for reflectors in this country, though the French, especially, have extensively employed gold-plated metal mirrors. Unfortunately, these are prone to warp out of shape, in addition to being heavy.

The manufacture of glass mirrors is carried on as follows: After a plane sheet of especially clear and colorless plate-glass has been rolled, annealed, and cut to a circular disk, it is heated over a former, and of its own weight bends to a fairly accurate parabolic shape. It is again annealed for some thirty to fifty

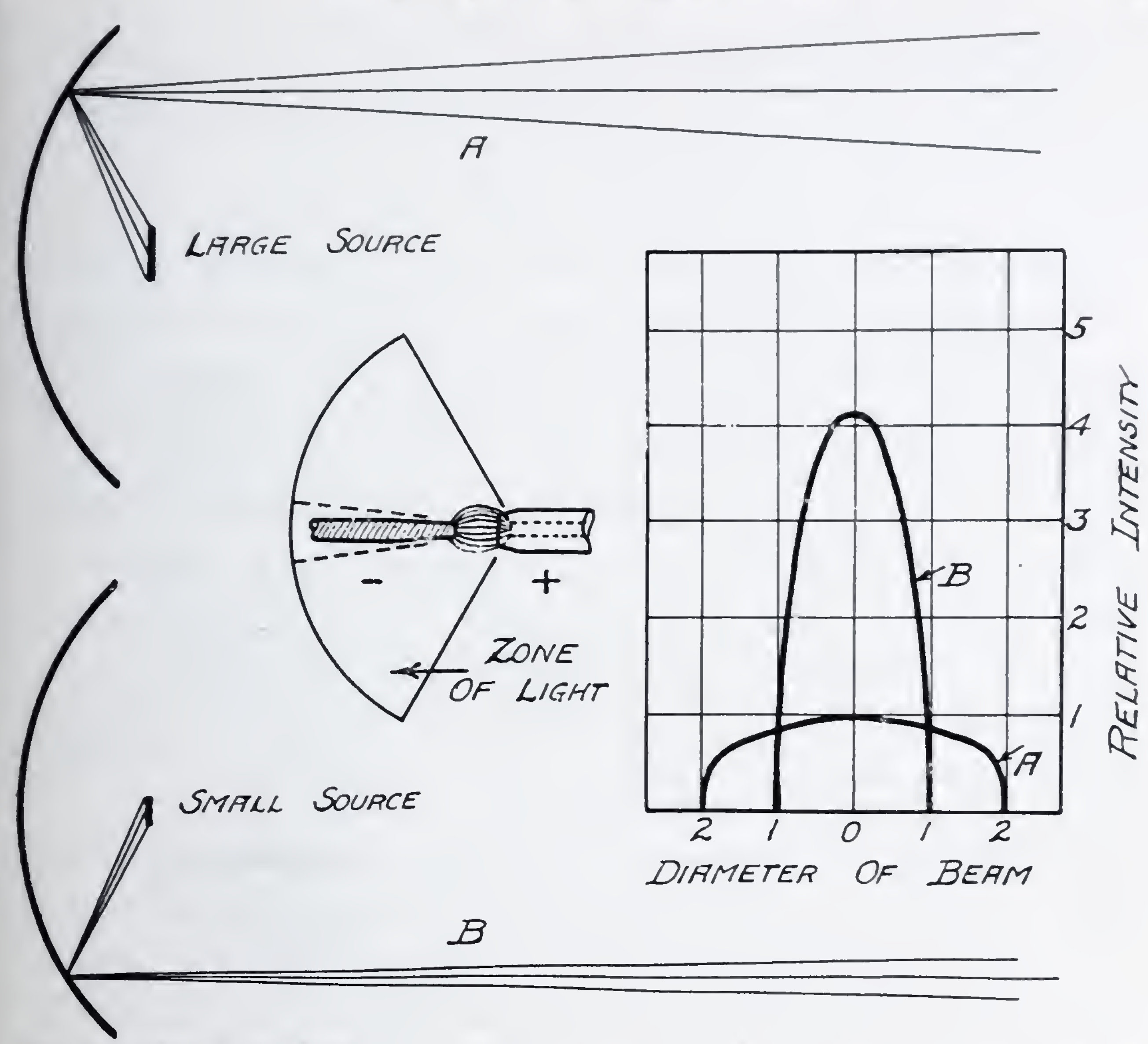

Fig. 7. The Distribution of Light from the Arc, and the Influence of the Size of the Light Source upon the Beam.
(*A* represents the beam from a source twice as large as *B*.)

hours, then ground and polished, and silvered upon the convex surface by immersing in a nitrate bath. Later, this silvered surface is built up by silver plating, then copper plated, and finally covered with a plastic paint in which a fine wire gauze is imbedded and baked in. It is then given a waterproof and heat resisting paint over all. Each mirror is tested for its optical properties by photographing the focal point of a pencil of light, and by photographing the reflection of a cross-ruled screen.

Dimensions of the glass mirrors are as follows:

Nominal size	Inside diam.	Outside diam.	Thickness	Depth	Focal length
30″	31–3/16″	31–17/32″	7/16″	5–1/2″	12–1/4″
36″	37″	37–1/4″	3/8″	6–1/4″	14–3/4″
60″	61–3/8″	61–21/32″	7/16″	9–23/32″	25–19/32″

Needless to say, these mirrors are expensive (a 60-inch costing in excess of $1000) and, worst of all, they are fragile. Three per week was the output of the United States before the war, increasing to 15 per week in 1918. Hence, early in the developments that are mentioned above, it was attempted to substitute metal mirrors for the glass ones. Experiments were extended over a year, and eventually the following process was evolved. First, a polished but unsilvered glass blank is given a light wash silvering, and then a silver plating by electricity. Then it is carefully and slowly copper plated to a thickness of about 0.03 inch (thirty to forty hours). The copper is then covered with an adhesive compound, and over this is built up a layer of plastic material, over which is laid a sheet-steel reinforcing frame. The reflector, complete, is removed from the glass blank, and after receiving a coat of transparent lacquer, is ready for mounting. The unit cost, in 1919, was about $400.

One great fault with these composite metal mirrors has been the maintenance of a good reflecting surface under the heat of the arc, the adverse weather conditions to which they must be directly exposed, and the chemical discoloring effects of the arc-light which is high in ultra-violet rays. When the surface lacquer has been perfected (a nice subject for future technical research) the metal mirrors can be counted on to replace the glass mirrors in all the large-sized searchlights.

One other pertinent problem has been the elimination of noise in the operation of both the arc mechanism and the power-plant. At first glance this might seem inconsequential, but one must reflect on the fact that at night the hostile aircraft is detected first by the noise of its engine, and, by an expert, its position can in this way be determined within a few degrees. No conflicting noises should embarrass the operators, least of all a noise very similar to that of the aeroplane.

It would be fatal to turn on the searchlight and begin sweeping the heavens at random, for the searchlight becomes the easy prey of the bombing plane that is not located and kept in the beam of light. When in the rear areas, say 10 miles behind the front lines, the direct hits by enemy artillery are negligible, but an exposed searchlight within range of 75-millimeter artillery

might exist one minute, but not longer, so that any disclosure of position is avoided to the utmost.

As for the arc mechanism, it must be regulated so that excess current will not cause hissing and flaming of the arc, and the artificial ventilation of the drum or barrel types must be by a silent motor, and with the air exhaust ports well muffled.

Making a quiet power-plant is a more difficult problem. It involved the use of extra-large mufflers, the elimination of all gearing, or, where such is necessary, the use of fiber gears and pinions, and the securing of all rattling parts.

Before a searchlight is placed in operation, or if at any time there is danger of its becoming a target, it is not feasible to have exposed lights of any sort around the mechanism, and this has led to an interesting side development of using radium luminous paints on several parts of the apparatus. The figures on the meter scales, for example, were painted with radium compounds, and a band of such paint was placed across the arc of the scale against which the instrument needle shows as in silhouette. Rings of luminous paint were made on switch handles, and all positions at which current or voltage should be maintained were unmistakably marked.

It is impossible in this short survey to go into the details of the "fool-proofing" of searchlights, but where there was one failure from outside sources or from actions of the enemy, there were a hundred from things done in the haste of getting into action, from nervousness under fire, or from hands unfamiliar with the mechanism. Just as illustrative of this point, all electrical connections had to be made irreversible (direct current) and where electric wiring was on the back of panels or concealed in the frame, these circuits were outlined on the exposed face in white paint. In an effort to eliminate breakage, switchboard panels were made of oil-treated asbestos fiber board ("transite") and hard rubber parts of plug connections were eliminated. Cushion rubber tires were used instead of pneumatic, carbon electrodes were packed in specially designed waterproof tin tubes, and even such precautions had to be taken as stenciling on each tank or container exactly what it should hold, and its capacity.

One can almost truthfully say that it is useless to put into the field any searchlight apparatus that cannot be repaired with a broken-handled pick, a piece of rusty barbed wire and a mess-kit knife.

When the European War began, most of our large searchlights were of the low-intensity types. These used large hand-fed carbons and required a large mirror; furthermore, with the large area of positive arc crater as the light source, the beam was not sharp and had too great a divergence or too great a penumbra of light, and consequent "ghosts." (See Fig. 7.)

The characteristics of the low-intensity arc carbons used in barrel-type searchlights were as follows:

Search-light mirror diam.	Rated current amperes	Carbons pos.	Carbons neg.	Copper coat neg.	Cores pos. and neg.
60″	175	2x15″	1–3/8x12″	none	cored
36″	110	1–1/4x12″	1x7″	light	cored
30″	80	1–1/8″x12″	7/8x7″	light	cored
24″	50	15/16″x12″	13/16x7″	light	cored
13″	20	5/8″x6″	1/2x4–1/2″	light	solid

All carbons were tapered and cratered before packing—obviously, so they would immediately burn at normal characteristics. The average burning ratios and useful life were as follows:

Size of searchlight	Burning ratio positive to negative	Useful life
60″	1.5 to 1.0	5 hrs.
36″, 30″, 24″	1.3 to 1.0	4 hrs.
13″	1.3 to 1.0	3 hrs.

The low-intensity arcs had a current density of about 0.1 ampere per square millimeter.

In between the earlier and the latest developments we had the so-called medium-intensity arcs which were a species of compromise influenced by European practice and by carbon manufacturing difficulties. These had four times the current density of the low-intensity types; that is 0.4 ampere per square millimeter.

All searchlight carbons of good quality came from Germany before the war. We are now making in this country carbons of greatly improved quality, and for all present searchlight models.

The highest development in light generation for projection purposes has been attained in the high-intensity arc, which uses a 7/16-inch diameter negative carbon (8 inches long) and a 5/8-inch diameter positive (15 inches long). Temperature of the arc crater increased from 3500 degrees C., absolute, of the medium-intensity arc to over 5000 degrees C., absolute, in the high intensity. Fig. 8 shows the temperatures and brilliancies of several light sources.

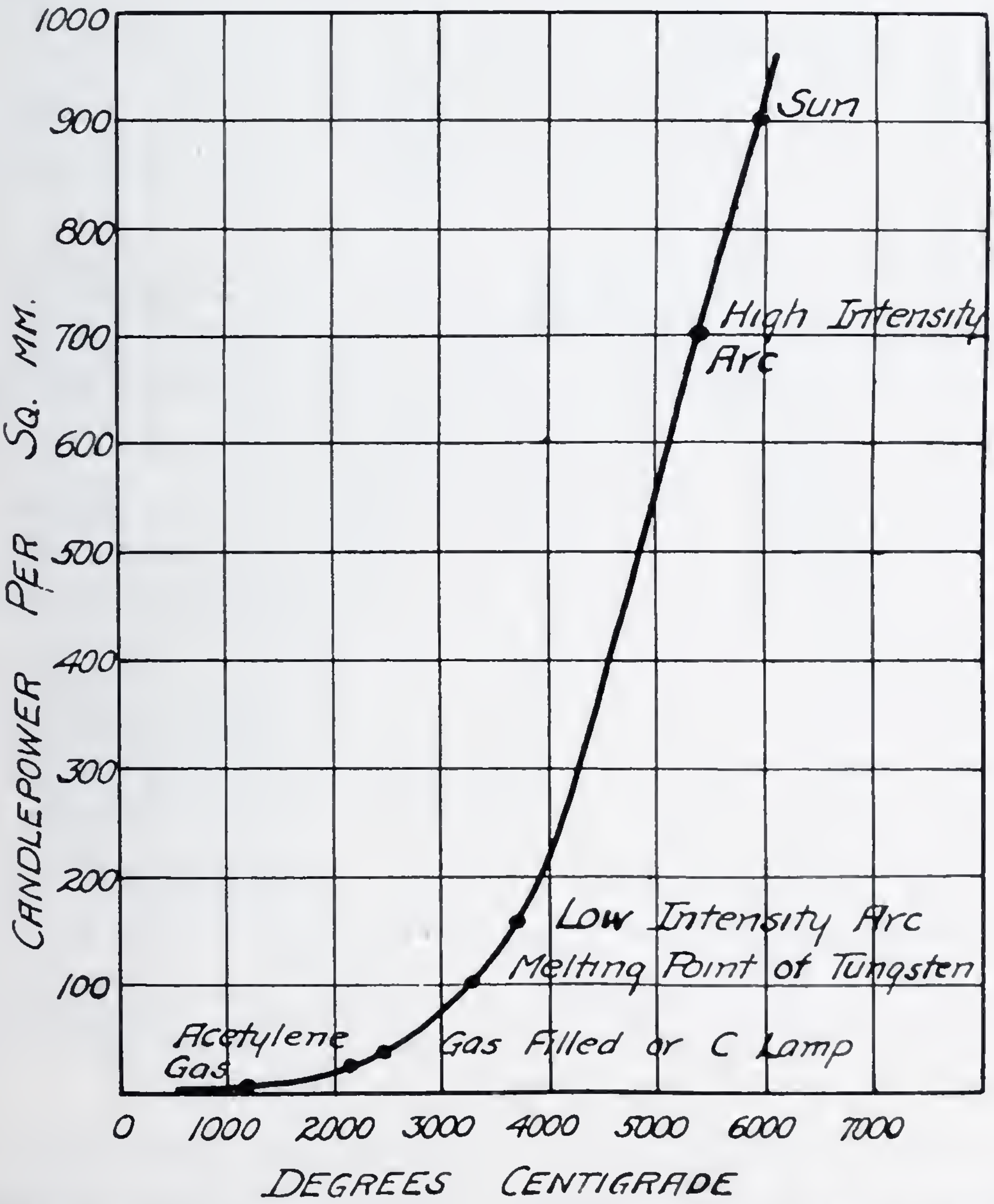

Fig. 8. Temperatures and Intrinsic Brilliancies of Several Light Sources.

Within the arc crater the gases reach a very high temperature from the great current density (150 amperes, or density of about 1.0 ampere per square millimeter). By a uniform, continuous

rotation of the positive carbon, the crater edges are maintained intact and the luminous gases likewise retained. Copper plating of the positive electrode assists the carrying of current and prevents arcing of the sliding contacts or the silver figures that convey the current to the carbons. A protective covering for the electrode near the arc reduces premature oxidation and spindling. The coring of the carbons is advisable for better cratering and burning. The softer cores in some cases are of powdered carbon, impregnated with neutral salts, but at the high temperature of the high-intensity arcs, the light is bluish white and is uninfluenced by the ingredients in the cores of the carbons.

The focusing and steadiness are assisted by the fixed relation of the arc to the positive crater and by keeping the crater at the same position. This matter of focusing is vital. Moving the positive crater 0.5 inch out of focus reduces the target illumination more than 65 per cent.

In one of the simplified designs, the rotation and feeding of the carbons is performed manually. By inclining the axis of steel toothed wheels that bear against the positive carbon, with respect to the axis of the carbon, it may be either fed forward or retarded as it is being rotated. The negative carbon is not rotated, merely being fed forward as it is burned, at a rate of about six inches per hour. An occulting cup or cover is provided (this referring especially to the dish-pan model) so that the arc may be struck and observed without allowing any of the light to reach the mirror. In order to eliminate the troublesome image of the arc flame, that otherwise would appear in the beam, a screen is provided to eclipse it. A small inclined chimney is attached to the arc head to carry off by natural draft the white fumes of the impregnated carbons. All of the arc control is effected from the rear of the mirror, the operator observing the image of the arc upon a small ground-glass plate close to its operating handles.

As to the intensity of the reflected beams from these recent searchlights, candlepower figures scarcely convey a lasting idea to the layman. When we speak of 150,000,000 candlepower we are talking in terms of brightness a million and a half times that of the usual incandescent electric lamp—well nigh beyond our comprehension. Another way of gaining a conception of the

illumination is to note that from a 150-ampere, high-intensity, 60-inch searchlight, the target at a range of roughly 1000 feet is lighted to a maximum of about 250 foot candles. (See Fig. 9.)

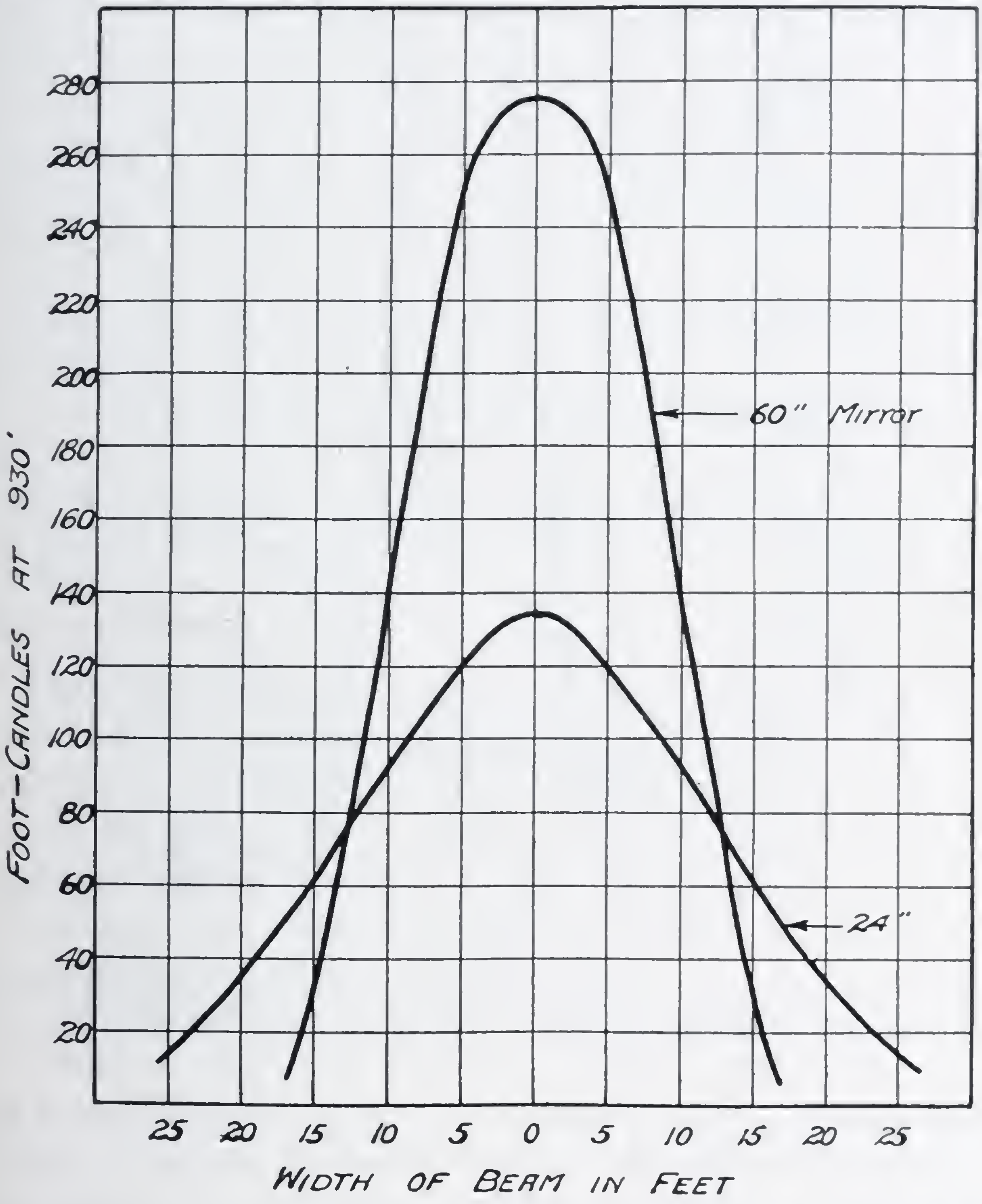

Fig. 9. Beam Characteristics of a High-Intensity Searchlight with 60-Inch and with 24-Inch Mirror.

The power of the 1917 models of searchlights as compared with the 1919 models is illustrated by Fig. 10, where curve *B* represents the former and *A* the latter.

"Seeing" with the searchlight is not without some peculiar features. Of course, candlepower *per se* is important, and other things being normal, it is no hard task to pick up a light colored

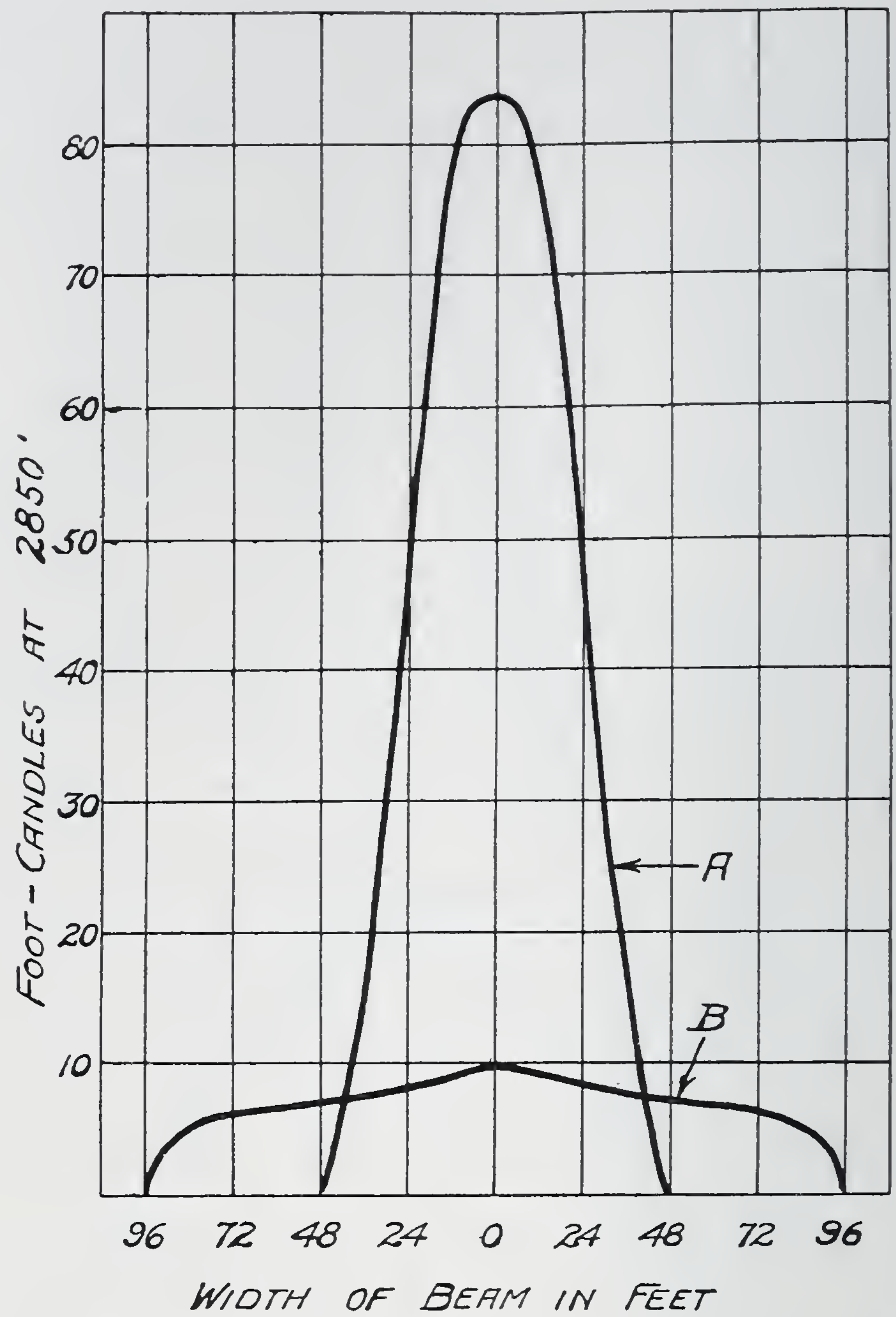

Fig. 10. Comparison of Beam Candlepower between *B*, the 1917 Low-Intensity Searchlight, and *A*, the 1919 High-Intensity Unit.

target such as a large areoplane at a range of three miles with a 100,000,000-candlepower beam. But first, the beam must be homogeneous, and appear as a narrow cone of light without any excess divergence. One and one-half degrees divergence either side of the axis is about the maximum for proper illumination of distant targets, but, be it said, the beams for swift scout aeroplanes should be a little more divergent, unless our control mechanism can be made more agile.

Since the chief function of the anti-aircraft light is to keep the object in the illuminated field and to blind the enemy, the beam must be uniform and intense. Clouded mirrors or dirty

front glasses will give annoying phantoms. A peculiar thing is true, that the beam itself will mask as well as reveal a target, and this effect, particularly in a slightly foggy atmosphere, is seriously detrimental. To an observer directly beside the searchlight a target will be invisible, while it will appear perfectly distinct to one a few hundred feet to either side of the searchlight. The percentage of "pick-up" of a plane at 4000 yards range varies from about 40 per cent. at 100 feet from the searchlight to 60 per cent. at 1000 feet from the searchlight.

Much has been said about the reddish-yellow colored light and its greater powers of penetration—in fact, the French army was at one time definitely committed to the use of the gold-plated mirror and its brownish light—but this has not entirely demonstrated its superiority in the field. One reason is that the aeroplane targets were grayish-blue or neutral colors and seemed to be picked up more easily with the bluish-white, high-intensity beams.

Where one deals with light projected at long ranges, the absorption losses in the atmosphere are considerable factors, and give birth to peculiar phenomena. From the investigations—which are not yet completed—the results indicate that the amount of light returned to an observer near the searchlight, varies inversely as the sixth or seventh power of the range. It has also been found that the shorter wave-lengths of light energy are absorbed more rapidly by the earth's atmosphere than are the longer wave-lengths—that is, the yellows and reds. Experiments with a 150-ampere high-intensity arc in a 60-inch glass mirror, showed the beam to appear distinctly yellow at 20 miles. Radiometer tests show that 75 per cent. of the light energy in the yellow part of the spectrum is dissipated in seven or eight miles of clear dry air near the earth's surface. Fig. 11 shows the effect of atmospheric absorption on a projected beam at several distances, *A* being air one mile thick, *B* two miles thick and *C* four miles thick.

Beam traversing is not easy, and necessitates a slow and uniform motion at the lamp, for, at a range of 5000 yards a motion of a degree per second means a speed of beam travel of over 87 yards per second—nearly three miles per minute.

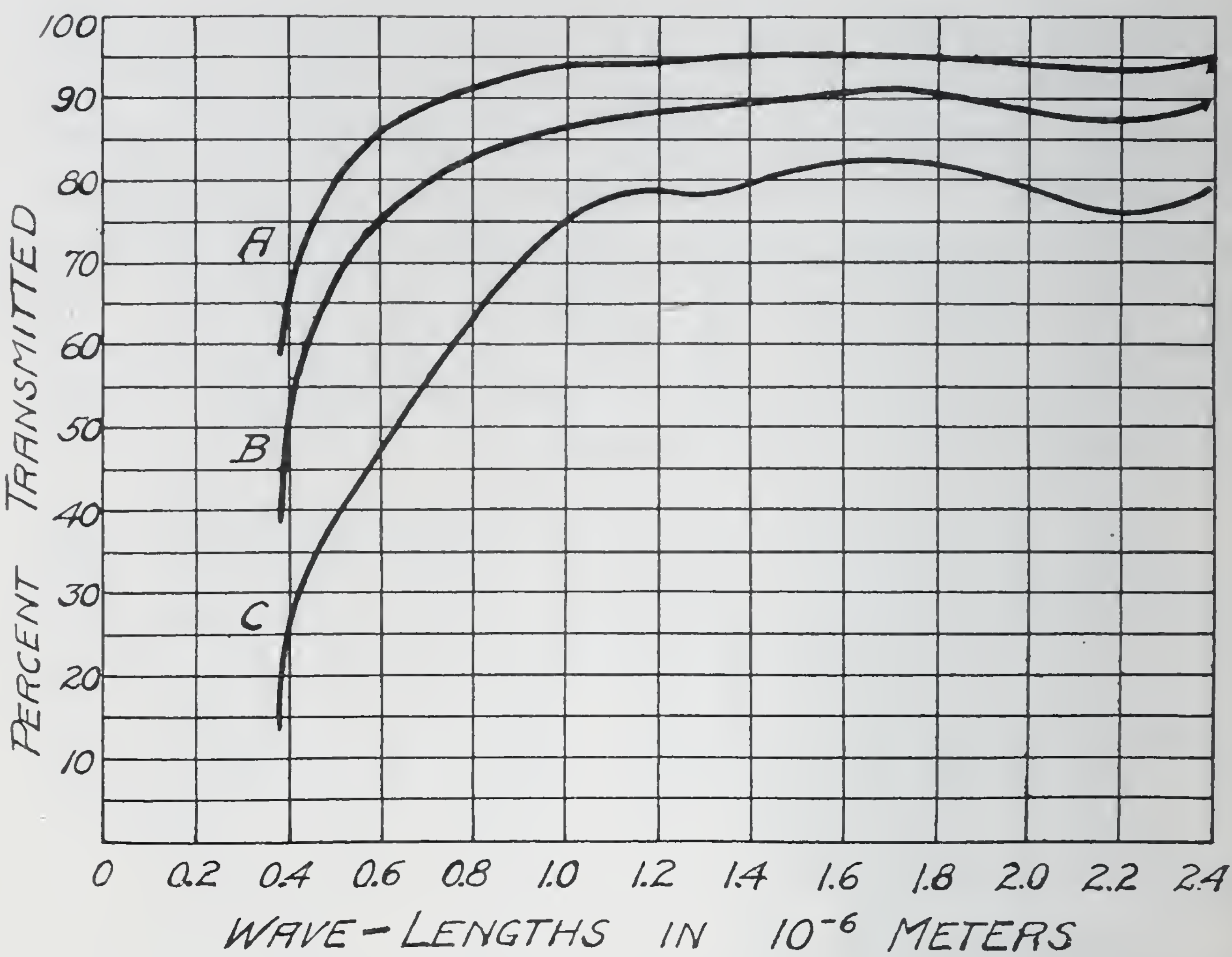

Fig. 11. The Absorption of the Light of a Searchlight Beam by the Atmosphere.

For future operations against aircraft, it seems probable that no projectors smaller than 60-inch, or 150-centimeter, mirror diameter will be satisfactory. The same arc (150 amperes) will give 275 foot-candles on a target at a 930-foot range if using a 60-inch mirror, but only 135 foot-candles when using a 24-inch mirror. Fig. 9 illustrates this difference. Development must still be made to eliminate "spill" light, and effect a better concealment of the source.

This brings up the question of invisible light—a problem solved to some extent during the latter part of 1918, but not completely so. This was purely a question of screening out the invisible radiations—roughly those from 0.4 μ to 0.7 μ—so that "invisible" luminous energy was projected and became visible when impinging upon a fluorescing target. The field of application is signaling and not the revelation of the ordinary target. Using a searchlight beam interrupted by the use of the venetian-

blind shutter, it is feasible to signal at several miles range, even in broad sunlight. Such signals would of course be invisible to an observer a few degrees outside of the actual beam.

Searchlight tactics will form a large part of future military maneuvers. Swiftly moving hostile aircraft along the "ceiling" above ordinary gun range, can be combated by this means only. Whether we have the League of Nations or not—whether we trust in battleships, or politics, or "scraps of paper"—there is no logic in closing our ears to the truth that the nations of the world are confronted with a new problem in warfare or "self-protection," if one desires a softer word. High-speed areoplanes can be sent hundreds of miles, distributing terrifying and death-dealing missiles throughout wide areas, and the searchlight is the only means of defense.

What we know of aerial warfare at present, indicates that correct defenses will consist of a band of lights, similar to that of Fig. 12, stretching along the entire exposed front and about

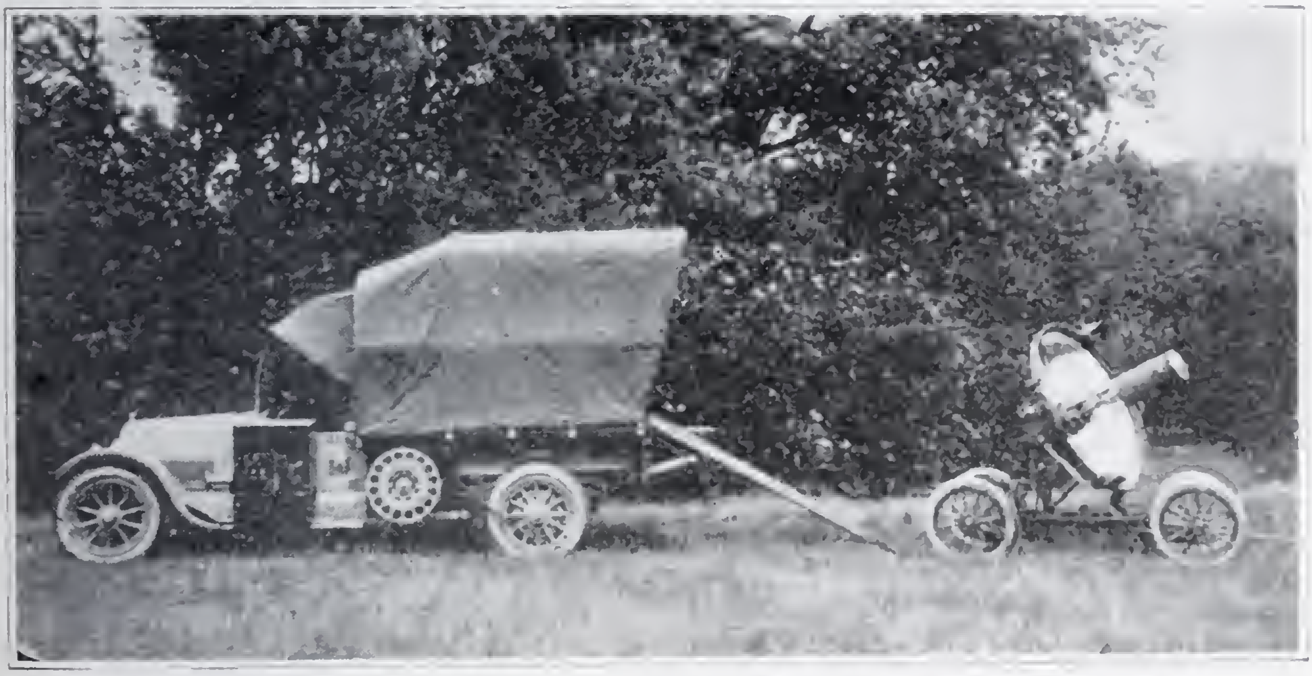

Fig. 12. Day View of a Complete 60-Inch Searchlight Outfit.

(When in operation, the power-plant can be sheltered in the comparative safety of darkness 300 feet from the light. When in transit, the power unit carries the searchlight and, on good roads, can attain a speed of 45 miles an hour.)

four searchlights deep. Operating in conjunction, will be sound-collecting paraboloids to locate hostile craft and limit the field of search of the searchlight beams. All emplacements, where the lights are dug in as shown in Fig. 13, should be within supporting

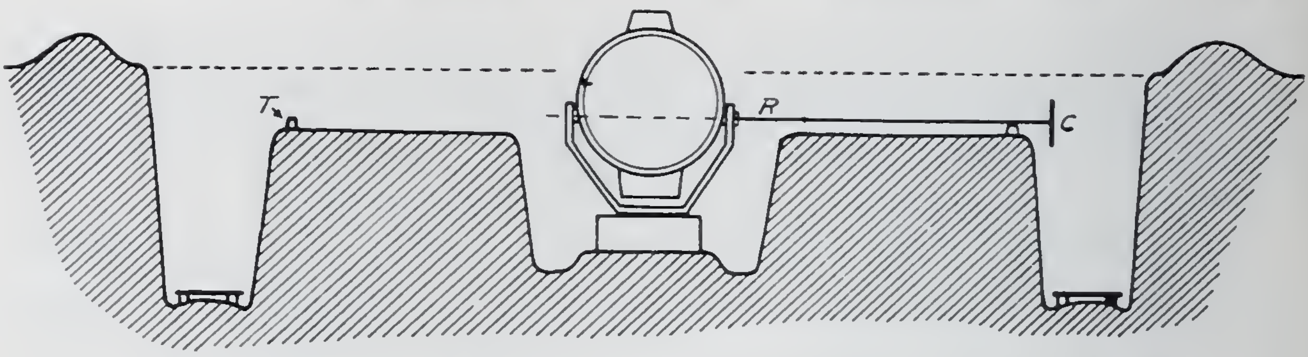

Fig. 13. A Typical Searchlight Emplacement as on the Western Front in 1918.

(The operator walks in a circular trench and directs the beam by means of the handle, *C*, the rod, *R*, of which rests on a circular track, *T*.)

distance of adjacent lights and preferably above ground mists. Searchlight positions ought to be from one to three miles apart, staggered, depending upon the terrain.

Along any line of defenses it should be possible to bring two and preferably three beams on any target over the area. These will dazzle and mislead hostile aviators and, by contrast, hide objectives. For future wars it is believed that arc searchlight tactics will center around aerial combat; in other words, will have little to do with illumination of the ground. Bombing attacks must be expected on a still greater scale, employing larger and larger planes, carrying projectiles containing thousands of pounds of explosives. Fast pursuit planes will doubtless work in conjunction with bombers to attack and confuse our defenses, such as searchlights; and air reconnaissance and "strafing" by night will be correspondingly increased in military value. All of this indicates the necessity of giving thought to this one great arm of defense—the searchlight.

In times of peace we can expect to see in the sky, before many years, searchlight beams of all sorts and colors, guiding aeroplanes as lighthouses now guide vessels. It has been determined that a vertically projected beam of white light from a 36-inch unit can be seen more than 25 miles distant, and this is the logical method of indicating landing fields and air lanes.

Modified searchlights or projectors are undergoing experiment relative to illuminating aerodromes, where the beam is projected against a large target, such as an inverted white cone, to enable the pilot to align his plane and judge his height unembarrassed by glare from exposed direct lights.

Long-distance communication can be maintained by beam signaling, for which no expensive receiving apparatus whatever is necessary. It is even possible to predict weather conditions by noting the disposition and character of air strata, as revealed in the searchlight beam.

Thus even after the cessation of war, our searchlight developments will bear fruit. Much yet remains undone, but so much has recently been accomplished that the story of searchlight progress reads like a twentieth century romance that will interest everyone.

DISCUSSION

Mr. S. E. Duff:* How do they co-ordinate that sound range-finder and the searchlight?

Lieut. S. G. Hibben: There were two means of using the sound ranging apparatus, resulting from two different types of devices used in the American Army. One was a microphone roughly consisting of a five-gallon milk can across an opening in the end of which were stretched small tungsten wires heated to a low temperature by constant electric current. The sound-wave impinging upon that can, rushing in and out past the wires, would momentarily cool those fine wires, changing the resistance of the circuit which would be recorded electrically at a central station and give the exact time at which that sound reached that particular station. Having five or six of those stations, you could easily determine the origin of that sound.

The other device was the reflecting paraboloid. The method was to sweep the heavens in the general direction of the noise, until the sound heard at the focus of the paraboloid was at its maximum, which would then indicate that the origin of the sound was on the extension of an imaginary line through the focal point of the paraboloid and, by this means, you could locate the plane within a few degrees.

The French used a combination of four large receiving horns like graphophone horns and by swinging them around they located the position of maximum sound. After having located the plane within a few degrees, the searchlight was turned on and with a very small rotation, or elevation, the operators found the plane itself in the beam. If they did not find the plane within a few seconds the searchlight was turned off.

Mr. S. E. Duff: The interesting thing to me was how they got the parallelism of the lines of sound waves and the searchlight beam.

*Consulting Engineer, Empire Building, Pittsburgh.

LIEUT. S. G. HIBBEN: The searchlight has two scales, an azimuth and an altitude scale. The azimuth scale was horizontal, and the altitude scale was set with a point of departure or reference on a definite part of the landscape like the steeple of a church or a tree top. If a report was given that an object was azimuth 30 and altitude 75 for example, it could be located at once.

MR. HOWARD L. BEACH:* I would like to make a few remarks to supplement what Lieut. Hibben has said in a very ably presented paper. Lieut. Hibben was connected with the design of the new searchlights, while I was in charge of the production of the searchlights for France as soon as they had been ordered and released by the Design Section, and there were many problems which arose from a production standpoint, entirely separate from those that were worrying the designers.

Before the war, all glass used for searchlight mirrors came from Germany and there was no product in America equal to the German. Americans were turning out a glass of equal quality in small pieces, but the searchlights required disks of this quality six feet in diameter.

My first introduction to this problem was in Rochester at the plant of the Bausch & Lomb Optical Company, where we were getting about one mirror a week to meet a requirement of ten. I found the inspectors turning down mirror after mirror. Inquiry as to their reasons for the rejections developed the fact that, according to past precedent, the least imperfection in the glass was sufficient to condemn it on the basis that imperfections distorted the beam of light. Being unacquainted with old military searchlights, my point of view was different from that of the old inspectors, and I began to analyze the situation from the standpoint of the entire searchlight, with the following results:

The source of light is from an electric arc produced between two carbon pencils, which are held in place by a mechanism located at the focal point of the mirror. The construction of the mechanism is such that it casts a shadow in the center of the mirror, thus reducing the efficiency of the mirror. The reflected beam from the mirror now passes through a glass door in the front of the

*Sales Engineer, Clark Car Co., Pittsburgh.

searchlight drum. Many of you have probably seen these glass doors, and have been impressed by the wonderful lens in front of the light. I know I was, and it was rather a shock to me when I found that this so-called lens in front of the searchlight was nothing more than a circular door made up of strips of quite ordinary plate-glass. It is built in this manner to reduce the cost of replacements, in case a strip becomes broken. The edges of the strips are supposed to be ground and slightly beveled. You can easily see that considerable distortion of the light beam was caused by the edges of the strip, not to speak of the absorption of light by the inferior quality of the plate-glass, and distortion by imperfections in the glass strips. This was not all, for in front of the glass door was a shutter like a venetian blind, which cast very perceptible shadows through the beam of light.

Taking all this into consideration, I decided that the small imperfections in the mirror glass were of very minor importance, and so long as they did not weaken the structure of the glass could be overlooked with impunity. Before the war closed, inspectors accepted mirrors that in peace times would have led to the court-martial of the inspector.

In order to improve the quality of our glass, the Pittsburgh Plate Glass Company spent a great deal of time, money and effort to obtain a glass equal to the product of the Germans before the war. In this, they were greatly assisted by Capt. W. S. Kilmer, an illuminating engineer in civil life. Capt. Kilmer was fortunately assigned to my section, and was sent by me to Pittsburgh as the Army representative to aid the Pittsburgh Plate Glass Company. The result of his and their efforts produced a glass not only equal, but superior to any shipped over from Europe before the war, and a great deal of credit belongs to the officials of the Pittsburgh Plate Glass Company for their painstaking work.

The first searchlight Lieut. Hibben showed on the screen this evening had something like 750 parts in the light itself, exclusive of the mast and the carriage upon which it was mounted. About 250 of these parts were screws ranging in size from a No. 2 machine screw to a ⅜-inch bolt. The tool cases that went with the searchlight had two or three sizes of screw-drivers, wrenches,

pliers, and special tools. You can easily imagine the language of poor Tommy Kolinski trying to repair and adjust a searchlight on the Western Front in France, in the winter, with such equipment as this. When the designers got through with the new light, there was one size screw (¼-inch) for one size bolt (⅜-inch).

Mr. D. W. Blakeslee:* May I make a few remarks from another viewpoint? I had the honor of being an officer in the Fifty-sixth Engineers in the French zone of advance during the 11 major operations. As Lieut. Hibben said, our lights were mostly French lights. The majority were B. B. T.'s† which were made for the American Army in Paris. The lamps were used in connection with trucks of army transport type equipped with generators picked up in Paris from various manufacturers.

There were about eight of those American-made lights used in our regiment. We had a full regiment, five platoons to a company, each platoon having three lamps. Those lamps were six Harleys and eight American-made Sperry G. E. and the remainder were B. B. T. with the exception of one British Siemens.

One of the questions which was raised was regarding the metal mirror with the yellow beam. We operated these side by side with the French silvered mirror and had more success with the yellow than they did with the white. This was largely due to the method of control which we adopted—the English type of control which consisted of a pipe extension from the trunnions of the searchlight, the operator being about fifteen feet from the lamp instead of directly behind it.

The matter regarding the use of the paraboloid illustrated in the photograph showing one of the speaker's emplacements, was not so simple as has been expressed. Due to the distance from the sound source, and because of the speed of the aeroplane, there is a large angle of lag in the sound time. This had to be compensated for by means of apparatus which was developed in France, largely by myself. These angles could have been calcu-

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†Barbier, Benard & Turenne, Rue Curial 82, Paris.

lated, but the men we had to work with, though largely technical men, as far as high-school and college training goes, would have taken too much time to make those calculations; therefore, it was necessary to develop a sort of plotting board so they could be automatically estimated. The ultimate arrangement was a sort of caliper shaped device on the plotting board on which was set the reading of the paraboloid, and the elevation angles could be corrected in three seconds. The course of the plane being followed on this plotting board for a few consecutive positions and the necessary corrections then being made, almost instantaneously by reading this chart, the beam of light was exposed at the correct angle and the target illuminated.

Mr. W. B. Spellmire:* Recently we listened to an interesting paper by Mr. Elwood Haynes, describing stellite—an alloy which resists all oxidizing and other staining influences. It occurs to me that the danger of breakage, and other difficulties incident to the use of glass, could be avoided by making reflectors of this so-called stainless steel. It would be interesting to know whether this material could be used, and its use would further eliminate the absorption losses in the glass.

Mr. Howard L. Beach: Stellite mirrors were given careful consideration, and orders were placed for experimental mirrors made from this material. The material is extremely expensive and is very brittle, and will of course, be smashed by a rifle ball quite as easily as glass. The cost was found to be considerably more than that of glass mirrors. The glass finally developed by the Pittsburgh Plate Glass Company had a very low light and heat absorption factor. It was quite different glass from any you see around in the show windows and is not made for general commercial purposes. Ordinary plate-glass is about ¼ inch thick, whereas the glass in a 60-inch mirror is nearly ½ inch thick; moreover, there is no surface that has a reflecting power equal to that of silver on the back of glass.

Mr. W. B. Spellmire: Then it is not a question of expense?

*Manager, General Electric Co., Pittsburgh.

Mr. Howard L. Beach: In time of war, expenses in general are not considered, so that if stellite mirrors were practical and superior to glass, they would have been used. Superiority, however, in this case must take into consideration the cost, since the cost has a direct bearing upon the length of time required to produce the article, and if a stellite mirror costs twice as much as a glass mirror, it is fairly reasonable to suppose that it is twice as hard to get; and, in time of war, it is a question of getting the light from a searchlight when you want it, and not having to wait for spare mirrors.

Lieut. S. G. Hibben: We found that any solid metal mirror sufficiently thick and heavy not to be warped by the temperature changes, was so great in weight as to be objectionable in transportation.

Mr. Howard L. Beach: In addition to other objections to metal mirrors, there is one serious objection in that they are very easily scratched. You can easily prove this by running your hand over the headlight reflector on your automobile. Glass is very hard and can be wiped off with impunity, thus allowing the exposed reflected surface to be kept clean.

There is a point of interest about the searchlight truck units that is worth mentioning. The Mack truck complete with the searchlight weighed something like ten tons. The Cadillac truck complete weighed about four and one-half tons. Lieut. Hibben states that the Mack truck could make 12 miles an hour. Maybe it could going down hill, but I have trailed one a good many miles and never could average better than 10, whereas, the Cadillac has been run up to 55 miles an hour. The design of the Mack truck, with the generator in front of the engine, made it very hard to steer, as it was unbalanced. The generator was permanently connected to the engine shaft, putting an additional fly-wheel effect on the engine, thus making change of speed difficult and wear and tear on clutches very heavy. A train of Mack trucks was started on a cross-country run to Florida, and a Cadillac truck left Washington about a week after the Mack trucks. The Cadillac caught the Mack trucks at Roanoke, going over the same roads.

Mr. A. E. Blake:* What kind of glass is used on those lenses you spoke of, describing them from the composition standpoint?

Mr. Howard L. Beach: The Pittsburgh Plate Glass Company obtained the formula for this glass, and during the war was very generous with it wherever it could be used for Government assistance. At the present, however, it would seem to me that the formula belongs to the company.

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CONSTRUCTION WORK BY CEMENT GUN METHODS

By Arthur J. White*

In presenting this paper for your consideration the author is desirous that it shall be devoted to actual accomplishments that have been obtained by the use of the cement gun on different types of construction work, rather than to theory and statistics of the different tests that have been carried out. A great many tests have been made by professors at different universities; also by the United States Bureau of Standards and the United States Bureau of Mines. While fully realizing the vital importance of these tests, we will pass them over for the time being, and deal with construction matters, though I shall be pleased to answer any questions relative to these tests.

One of the most interesting mechanical devices that has been brought before the engineering world for some time, and one that gives the most promise of changing types and methods of construction, is the device which the general public first saw at the Cement Show in New York in 1910, under the name of the cement gun.

Carl E. Akeley, best known to the world as a hunter and naturalist, and one of "Teddy" Roosevelt's greatest friends, conceived the idea that by the introduction of water, or the hydrating medium, into the cementitious material coincidentally with the deposit, he could prevent the setting or hardening of the material before its application.

We, as engineers, can very readily see where this is a great advantage, but apparently Mr. Akeley saw more clearly than the average engineer the absolute necessity for this. He therefore conceived the idea of introducing the water into a chambered nozzle through which the dry material, previously mixed, should be forced by compressed air, and it is on this principle that the machine is based. As a matter of fact, compressed air to a cement gun is like gasoline to an automobile; it is the whole life of it.

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Mr. Akeley's experimentation, carried on over a period of several years, showed the further advisability of dividing the material into small amounts, in order to prevent the clogging due to the introduction of too much material into the hose at one time. This resulted in the development of a method of intermittent feeding by means of a revolving feed wheel, which allows the intermittent action necessary.

The next governing principle of this machine is that of the locking and working chambers of a caisson, thus accomplishing the result of a continuous operation, as the working or discharge chamber is always under pressure, the supply of material being introduced through the upper chamber. (See Fig. 1.)

Fig. 1. Cement Gun.

The cement gun will thus be seen to be a pneumatically operated machine, dependent on the flow of air to obtain the desired results. This flow of air not only insures conveyance of the material to the nozzle, which may be located at a considerable distance and difference in elevation from the machine, but also the further beneficial result of having the material propelled by this pressure against the surface to be covered, thus insuring a permanency and density far in excess of any other method. In many instances, this means the elimination of heavy and expensive

forms, for the material builds up against the backing to a considerable thickness without injury. It has been found that it is not advisable to apply more than two inches in one application as gravity will pull it loose.

In operating, the material is first mixed dry and placed in the upper chamber of the machine from which it travels in consecutive stages to the lower chamber, and thence through the hose to the nozzle. The water is introduced through the walls of the nozzle in needle jets under higher pressure than the air, thereby causing these jets to puncture this stream of flowing material. The action in the main hose causes the water from these jets to become atomized, resulting in the covering of all the particles with a fine spray.

When this hydrated material is impelled against the surface to be coated, the first effect is to cause a very marked rejection of material, which we call "rebound," which upon examination has proved to be sand, showing that the cement has adhered to the surface forming a film of neat cement which acts as a matrix. When this matrix assumes a perceptible thickness, the sand finds a seat or bed, and the rejected material, or rebound, grows markedly less. There continues a certain amount of rejection of this inert material, each grain of which, however, has performed the function of acting as a tamper to drive the preceding grains deeper into the matrix in which they are seated. The result of this pounding action is to produce a very dense, hard, and durable mortar which has been given the name of gunite.

Although this rebound has a definite and useful action, it also presents a difficulty which must at all times be reckoned with in order to insure proper and satisfactory results.

Different elevations and different work require different air pressures at the gun, and these figures are obtainable only through past experiences. When the correct air pressure has been obtained (the calculation depending on the class of work to be performed) it will mean that the impelled material must have sufficient velocity to result in the rebound being thrown back sufficiently to clear the reinforcing steel. If, on the other hand, the pressure employed is lower than it should be, this rebounding material lacks sufficient velocity and causes it to flow behind the

reinforcing wire or steel and lie in loose piles forming what are termed as "sand pockets." Sand pockets are very serious and must be guarded against if successful work is to be executed. In cases where the material is shot into confined spaces, and under unusual conditions, great care must be exercised and methods developed to overcome this defect; otherwise, the work will result in a failure, since no fixed rule can be stated to overcome the various difficulties.

The cement gun method of construction offers several advantages to the engineer.

The material produced is infinitely stronger in all tests than any concrete or hand-placed mixture yet produced, thereby permitting a very considerable reduction in section.

In spite of the greater strength of the product, the cement gun method is not expected to supersede ordinary concrete construction for every purpose. It is too slow and too expensive for heavy work, but its proper field of service will be indicated by the examples in this paper.

It has been proven beyond all doubt that the joint between the new and old sections of gunite is as strong as the gunite itself, and between old poured concrete and gunite it is stronger than the concrete. An interesting proof of this was developed on some work in Arizona a short time ago. A concrete girder was poured and allowed to cure for several days, after which a gunite knob was shot on the side of this girder, the surface, of course, having previously been cleaned and thoroughly wetted down. The top of this gunite knob was smoothed off to act as a fulcrum, and sufficient leverage was applied to break down the section. Instead of the break occuring along the cleavage line between the gunite and the concrete the fracture took place within the poured concrete itself.

Fig. 2 shows the Rapid Transit bridge at Long Island, N. Y. We all know the effect which locomotive exhaust has on steel, and owing to the steel being subject to such severe corrosion through locomotive blasts, it was decided to incase every piece of steel with gunite.

Fig. 2. Rapid Transit Bridge, Long Island, N. Y.

Comparative weights of beam incasement:

Size of beam in inches	Weight of poured incasement in pounds	Weight of gunite incasement in pounds	Percentage saved
8	82	38	54
10	102	42	59
12	128	64	50
15	187	89	52
18	228	94	59
20	260	122	53

The following advantages are presented:

1. Gunite incasement is superior, owing to its density.

2. Owing to its perfect adhesion, locomotive gases cannot attack the steel.

3. Forms are practically eliminated. Only a few shooting strips are needed to obtain square corners.

4. There is a considerable reduction in dead load as compared with poured concrete.

Fig. 3. C. R. I. & P. Track Elevation, Chicago. General View of Main Girders.

Fig. 4. Method of Obtaining Straight Lines.

Fig. 3–4 show the main deck girders of the track elevation of the Chicago, Rock Island & Pacific Railroad, in Chicago, at Seventy-ninth Street. All deck girders, floor beams, etc., on this job were incased with gunite. In fact, every piece of steel that went into this viaduct was incased. Of course, we can readily see that the initial cost is greater than painting; but, once done, maintenance costs are eliminated.

Another type of steel protection is the work done on a railroad bridge at Grand Crossing, Chicago, this also being protection from locomotive exhaust. The construction of this bridge was rather out of the ordinary. Speed was demanded; labor was scarce; wages were high. There was an enormous amount of traffic going under and over this bridge during the construction, and no interruptions were allowed. Therefore, instead of using expensive forms for the floor system, eight-inch I-beams were put in on 18-inch centers. Between these I-beams there was placed a piece of "ferroinclave," arched with a rise of eight inches, and resting on the bottom flange of the I-beam. This "ferroinclave" was left in, and, to protect it, the cement gun was used to give it a thorough protective coating.

These illustrations of protecting steel work in this manner are only a few of the many notable structures that have been so treated. Among other work must be mentioned all the steel members of the Woolworth Building, New York; all steel work in the power-plant of the Ford Motor Company, Detroit (Fig. 5); and the Colfax-Lorimer viaduct in Denver.

Fig. 5. Roof Construction, Ford Motor Company, Detroit.

The commercial side of building construction is perhaps most interesting to us as engineers, however. Low initial cost sometimes makes a greater appeal to those contemplating building than

does low ultimate cost. Some people are not able to foresee and calculate the cost of maintenance required on structural work. This state of affairs has, perhaps, been responsible for the wide use of corrugated metal for roofing and inclosing not only warehouses but various types of industrial buildings. Such material is short-lived unless thoroughly maintained by protective paint, and the necessity of annually renewing such protective applications piles up maintenance costs which, if added to the initial cost of the structures, would soon reach an amount greater than would have been necessary to build for permanence and eliminate these burdensome charges.

Concrete has been gaining popularity in various ways during late years, yet many are still unconvinced that in factory or warehouse construction, for instance, it can successfully compete with so-called mill construction.

The cement gun process makes it possible to build thin walls, thoroughly reinforced to resist temperature stresses, and dense enough to be entirely waterproof, at such a moderate cost that one can hardly afford to consider wood or metal sheathing, in view of the perishable nature of these materials, to say nothing of the continual expense of keeping them in serviceable condition.

Millions of dollars now go up in smoke annually, as a result of fires which could be prevented or more successfully combated by fire-resisting if not strictly fireproof construction. The South, as well as other sections of the country, is in need of more nearly permanent construction and more effective construction to resist fire. This is particularly true of some sections where the cotton crop needs safe warehouse protection not only against fire, but also against exposure to weather, which results in considerable loss when cotton must be held to wait a favorable market, under such conditions as have prevailed during the past year as a consequence of the European war.

Warehouse facilities in approximately 3000 market towns have been needed for years. The South never could see its way clear to tackle this enormous volume of construction of buildings of some general type; but, if the suggestions above are investigated and the recommendations and experiences of others carefully followed, the solution of the South's warehousing problem

is at hand. From the investment standpoint alone, such construction pays in its permanence and the elimination of maintenance expenditures, to say nothing of resulting in much more favorable insurance rates, which soon offset any slightly increased first cost.

As proof of this, take the new structures of the Galveston Compress and Warehouse Company, completed last year. The owners of the new cotton handling plant at Galveston had paid something over $1,000,000 in insurance premiums and had received only $85,000 in fire losses during their experience as cotton handlers. This made them realize the necessity of paying insurance to themselves, as it were, through fireproof construction. They therefore decided to spend their money in a more consistent manner, and put up fireproof buildings of high character, built of concrete. These have actually proved the most economical. Because of concrete construction, the rate of insurance on the Galveston Cotton Compress and Warehouse Company's plant has been reduced from $1.78 to $0.45 per annum—a saving of 75 per cent., or what would have amounted to $750,000 for the period during which they paid $1,000,000 in premiums. The plant which effected this saving, cost only $300,000 to build.

Gig. 6. Lining of Parabolic Coal Bunker.

Fig. 6 shows the inside of a coal bunker. In the opinion of the author, this is one part of an industrial plant which is sorely neglected. Steel in coal bunkers receives a large amount of wear and tear, not only with wet coal and the sulphurous action on the steel, but also due to the abrasive action of the coal on the steel. Several methods have been tried for preservation of this steel, but the author feels very safe in saying that the one that has been most successful and most economical is to line coal bunkers with gunite. Owing to its very density and its close adhesion to the steel, it can be readily seen that it is an excellent method of protection.

Another type of bunker construction which has been widely used is the parabolic bunker, hanging like a bag. When these bunkers are loaded to capacity, the steel conforms to the load, but with all the large number of instances using this style of bunker, I can truthfully say that we have never had any evidence of any breaking or cracking due to the elasticity of the steel.

There is also another type of bunker, different in design from the last two mentioned, and that is a patented bunker constructed of steel bands hung in parabolic shape, on which is fastened "hy-rib" or "ferroinclave." Several of these bunkers have been constructed with the cement gun, and in some instances the thickness of the coating has been as much as six inches. These have all proven very successful. Lining coal bunkers when first built is becoming quite a common practice.

Steel over blast-furnace slag pits has to be watched very carefully, and, when painted, the maintenance cost is very high, whereas, with a little extra cost at the start, this steel could be protected permanently, and I am sure it would relieve a lot of engineers of one big worry. No doubt we have in the audience some engineers who have experienced this kind of trouble.

Fig. 7 is very interesting. It shows 16 gas purifying tanks of the Peoples Gas Light & Coke Company, in Chicago. Owing to the enormous demand for gas, which in this instance is artificially produced gas, it was found necessary either to construct 12 tanks to take care of their peak-load capacity, or in some way protect the 16 existing tanks so that an even temperature could be maintained. The author is not very well versed in chemistry,

Fig. 7. Tank Insulation, Peoples Gas, Light & Coke Company, Chicago.

but believes that together with the iron oxid which is deposited inside those tanks, steam has to be injected, resulting in a chemical action taking place, thereby purifying the gas. During the extreme cold weather, it was a constant source of worry to the engineers to maintain an even steam pressure, which had to be kept up to 95 pounds, and, which I might add, constitute a very expensive item. Owing to the exorbitant price of steel and the scarcity of labor, the engineers looked around for some method by which they could protect these tanks from the extreme cold weather. The method adopted is as follows:

A three-inch cork insulation was first placed next to the steel on both sides and tops. This cork was held in place by cables, and hot pitch was applied to the joints. Over this was placed a layer of wire mesh, and gunite was then shot on to a thickness of 1¼ inches. The result was very gratifying as they could purify more gas in considerably less time and the steam bill was cut practically in half.

Fig. 8 shows a group of oil tanks at the Standard Oil Company's plant at Whiting, Ind. These were treated exactly as described above; but the idea of incasing these tanks was for the purpose of keeping the cold in, whereas in the previous ones the cold had to be kept out. The tanks contain the residue of crude oil which is put into a tank at a temperature of about 120

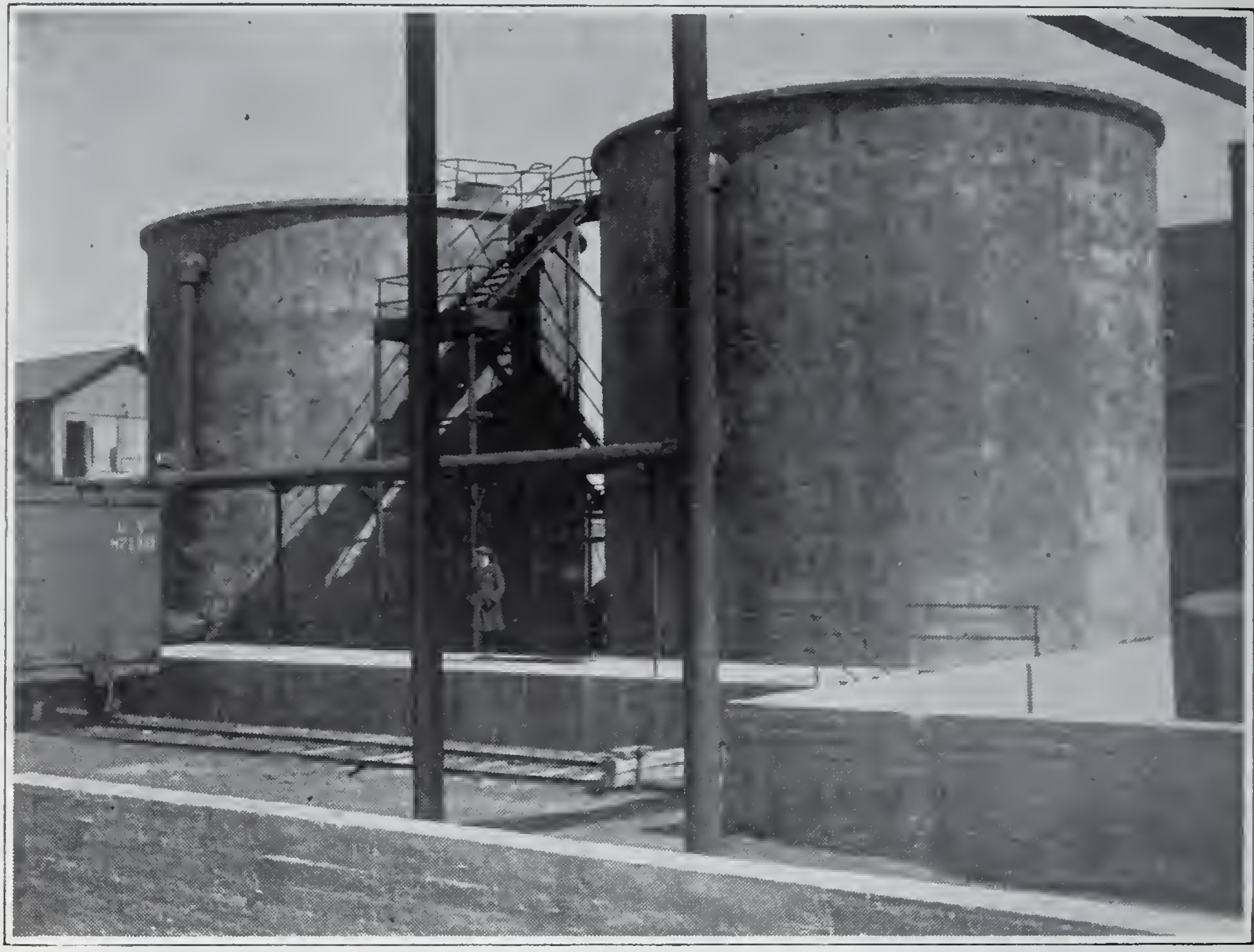

Fig. 8. Tank Insulation, Standard Oil Company, Whiting, Ind.

degrees. It then has to be frozen down to a temperature of 20 degrees, after which they take off polarine, vaseline, etc. To illustrate further the saving made by incasing these tanks it was shown in subsequent tests carried out that they could freeze down an 800-barrel tank in 24 hours; whereas, before this coating was applied, it took from 48 to 72 hours to freeze it—that is, during the summer months.

We now come to a problem which presented considerable difficulty, and the results obtained along this line with the cement gun have been very interesting. I refer to steel protection in acid plants, and I have in mind a sulphuric acid house of the Mineral Point Zinc Company, at Depue, Ill. As can be imagined, the fumes from acid manufacturing processes were very destructive to the metal. The building itself was originally covered with corrugated sheet steel. At the end of 2½ years the roof had been entirely eaten away and the side walls were so badly corroded that immediate replacement became necessary.

Before commencing work, the entire corrugated metal roof and side walls were removed and the structural steel members

were thoroughly cleaned of rust and surface oxidation by sand-blast. American Steel & Wire Company's triangular mesh was stretched from girt to girt and a temporary backing of boards placed on the inside, spaced about one inch from the steel wire mesh. The wall was then built up to two-inch thickness by forcing the mixed materials from the cement gun against this backing and fabric. This work has stood long enough to prove that the walls are entirely weather-proof, and no cracks have developed as a result of temperature stresses. Poultry netting was wrapped around purlins and these were entirely incased with gunite applied so that the entire roof structure, including steel purlins, has been covered with what practically amounts to monolithic concrete. Where the corrugated metal on the sides was still intact, it was left in place and used as backing, wire was stretched over it and gunite shot through from the outside. Where the metal had been so badly corroded that it could not be used for backing, temporary forms were erected to answer the same purpose. The entire building was covered in this way. The cost in this case was only 50 per cent. greater than the cost of replacement with the corroded metal. The advantages, however, lie in the fact that the structural steel will be protected against further corrosion and there will be no maintenance necessary to keep the structure in condition equal to that when the renovation was finished.

This job was done a matter of four years ago, and at the present time it is just as good as ever. As the result of a recent examination it was found that there was not even a rust spot on the inside that would indicate that any of the sulphuric acid had attacked the steel.

The first extensive job done with the cement gun was on the water storage reservoir supplying the town of Muscatine, Iowa (Fig. 9). You will notice that this is a bowl with a concrete retaining wall on the top. You will also notice that reinforcing wire mesh has been spread over the slopes and the bottom. The whole area, was given a two-inch coat of gunite, the retaining wall being coated to a thickness of one inch. In this particular instance the basin was constructed in five slabs, there being expansion joints only in four mitred corners, and along the line where the slopes and the bottom meet.

Fig. 9. Reservoir, Muscatine, Iowa.

Gunite has peculiar characteristics of its own, and, providing that it is properly reinforced, we can practically ignore expansion and contraction. In my opinion it was wrong to put in the contraction and expansion joints, in the installation just mentioned. Take a slab of gunite, let it thoroughly cure, and then put a microscope on it, and you will see that it is split up into thousands of hair cracks, each of which penetrates to a depth of, say 1/32 or 1/16 of an inch, and which do not take water. It is my opinion that the contraction and expansion of gunite are taken up by these minute hair cracks. This has been demonstrated time and time again on construction work under my supervision.

Another job where the cement gun was extensively used was on the Norfolk army supply base. It was a stupendous undertaking, which cost around $40,000,000. These terminals were built by the Government. They are situated on a site which is about six miles from the city of Norfolk, Va., on Hampton Roads, and cover about 640 acres. There are six warehouses, none of which is less than 1400 feet long, and several of which are 1680 feet long. In the larger Eastern cities such as New York, Bos-

ton, Baltimore, and Philadelphia, the Government constructed its warehouses on the perpendicular plan—that is, story upon story —this architectural plan being necessary because of the lack of ground space and the value of the land in those cities. In Norfolk the Government had the use of a vast area on the shores of Hampton Roads, and it built the warehouses at the army supply base on the horizontal plan, each one of the eight buildings being long and low and of only one story.

The one-story warehouse affords greater facility in the handling of all manner of shipments and eliminates all elevator service. The warehouses at the army supply base near Norfolk are completely equipped with electrically operated machinery for transporting supplies from the warehouses to the ships at the piers, and the ships are loaded and unloaded, also, by electrical machinery. Being thus equipped, vessels can be loaded and unloaded at these terminals in one-sixth of the time usually required at other terminals. Construction work on some of these Government buildings is illustrated in Fig. 10–12.

When beginning the construction of the Government warehouses at various points, in 1917 and 1918, the transportation system of the country was seriously congested, and construction had to be confined to the use of such materials and to the employment of such designs as would cause the least possible burden to

Fig. 10. Government Buildings, San Antonio, Tex.

Fig. 11. Gunite Roof Construction, Army Base, Norfolk, Va.

Fig. 12. Warehouses, Army Base, Norfolk, Va.

railroad service. It was first decided to construct these warehouses of tile. The weight of eight-inch tile that would be required to build the walls proposed for this army base exceeded 16,000 tons. Since tile had to be hauled a considerable distance by rail, and sand was plentiful, it was decided to begin to build the warehouses of gunite. From this it will be seen that about three-fourths of the bulk and the weight of the material required for the gunite walls would consist of sand. By adopting this method, transportation of materials was limited to cement, and the necessary reinforcing wire. An order was placed with the Cement Gun Construction Company for the gunite walls of only one of these warehouses, leaving the decision open as to the construction of the other warehouses until the success of the cement gun had been fully and openly demonstrated.

Eight of these warehouses are wooden frame with gunite walls. In one, the walls consist of tile, and it was deemed necessary to stucco this tile on the outside with the cement gun in order to render the walls thoroughly waterproof.

The construction of these warehouses consists of wooden frame; and wooden posts, 10 inches on centers, carried girts, caps, and roof joints. To the posts and girts there is secured American Steel & Wire Company's 0.068 triangular mesh. This wire mesh is held in place by wire nails and so-called wire chairs.

Wooden forms were placed on the inside of the building about one-half inch away from the mesh. Gunite was then shot into place from the outside to a total thickness of two inches. This makes a two-inch reinforced concrete wall of great strength and density, with the wire mesh reinforcement nearly in the center. The total length of all walls formed by the cement gun method on this job is approximately 20,000 lineal feet, 16 feet high. The area is approximately 500,000 square feet. While the original order was placed for only one of the buildings, the first work done was so favorably regarded that the order was extended to cover all six warehouses, including also a gunite weather protection on the tile building mentioned above.

In addition to these warehouses, there were constructed two piers which extended into Hampton Roads a length of 1280 feet. Each of these two sheds consists of one center bay and two side bays.

The center bay extends above the roof of the side bays to form a monitor. There is an outside wall extending from the top of the parapet down about 11 feet, below which is a continuous line of doors. On each side of the center bay, and extending from the monitor windows down about 12 feet to a point below the side bay roof trusses, are curtain walls acting as smoke deflecting walls and screens. The roofs of the side bays are of slow-burning wood construction, similar to the warehouse roofs. The center bays of these two piers, however, have gunite roofs. The roof structure over the center bay consist of I-beam purlins. Forms were placed between these I-beams snug up against the under side of the flange. The wire mesh was placed in continuous ribbons running between the eaves and supported on the

wire chairs three-quarters of an inch above the I-beams, with a dip or camber of about one-half inch toward the center of the span. The thickness of the gunite is 2¼ inches. A test panel of this roof showed remarkable strength. With a uniformly distributed load of 164 pounds per square foot, there was a deflection of five-eighths of an inch, with slight cracking. The load was increased, and at 209 pounds per square foot the deflection was 1⅝ inches at the center, with many cracks perceptible on the under side; but, when the load was removed, the slab came back to its original position, with no damage perceptible on the top side. This merely shows that the only action that had taken place under this test was that the steel was stretched to its elastic limit. Let us look into the advantages that may be gained, when an engineer can design his roof load on a basis of 25 pounds per square foot—of course, not including the wind and snow load. It means a saving of steel from the foundation up. This supply base construction is regarded as a remarkable achievement, and various contractors, builders, and others have declared that Norfolk possesses terminal shipping facilities that are both unique and incomparable.

I would like to go back and go into one more point on the cement gun method of stuccoing tile. One of the most serious defects in tile construction has been the inability to secure a proper bond between the tile and the stucco. I think it can be safely said that the cement gun has solved that problem. Care, however, should be taken to see that no waterproof compounds are applied to the tile prior to placing the gunite, because the presence of this film prevents the cement from being driven into the pores of the tiling and, consequently, causes lack of adhesion.

Fig. 13 shows a steel stack of the pumping plant of the South Works of the Illinois Steel Company, South Chicago, Ill. Rather than tear down a steel stack—which was in condition requiring renewal—thereby causing a shut down of the pumping station, it was decided to use the cement gun in reconstructing the stack. By coating the outside with reinforced, cement gun concrete, a new self-supporting stack has been built up. The steel stack was 175 feet high and 9 feet in diameter. The reinforcing net work consisting of rods and triangular mesh was built up around the

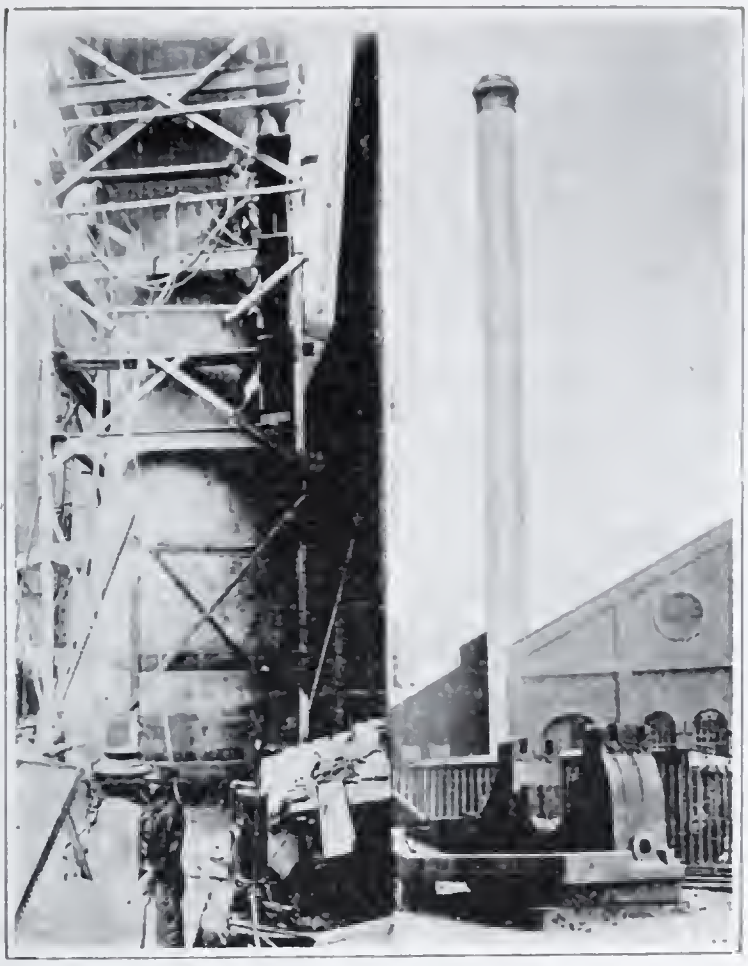

Fig. 13. Gunite Stack, Illinois Steel Company, South Chicago, Ill.

steel shell, and the cement gun concrete or gunite applied 18 inches thick at the base, tapering quickly to 6 inches just above the base and then gradually to 4 inches at the top. The heavy section at the bottom was applied in three layers, while that part above the base was applied in one operation. Square, twisted, reinforcing rods of suitable strength, depending on the section and the height, were placed vertically at varying distances as the work progressed upwards.

Progress averaged 10 feet in height per day, with a working crew of seven men. The result is an inexpensive solution of a difficult problem, affording a pleasing appearance and rapidity of construction. Work was done under the direction of Mr. J. F. Brown, Civil Engineer at the South Works. An interesting fact in connection with the stack construction is that the concrete was applied when the steel was almost too hot to touch with the bare hand. The intake or breeching extending from the side of the boiler house to the stack was also incased with a three-inch layer of concrete, while this breeching was so hot that water thrown on it boiled.

This method of construction has proven very successful. Not only is it cheaper, but the stack can be kept in operation during the time of construction. Of course where forced draft is used, and the temperature at the base of the stack is around 1000 degrees F. some sort of insulating material, such as asbestos, must be used between the steel stack and the gunite sheath.

Broken masonry can be successfully repaired by the cement gun method. One interesting repair job was on a tunnel through a limestone mountain. No protection whatsoever was provided, and in due course of time, as the air affected the rock, there would sometimes be a rock fall of between 60 and 100 tons. The engineers of the Illinois Central Railroad called in the engineers of the Cement Gun Construction Company and asked what they could do. Prior to this, bids were asked from several contractors for placing a 12-inch lining inside this tunnel. The figures varied from $65,000 to $100,000. After some very exhaustive tests, the railroad engineers asked the Cement Gun Construction Company for a bid to place a two-inch lining over this rock to conform to the contour of the rock. The main idea was not to provide weight and strength of concrete to hold up the disintegrating rock, but to exclude air and thus prevent loosening up the rock formation. Eventually, the contract was let to the Cement Gun Construction Company and a two-inch coat was put over the whole inside of this tunnel, at a figure very much below what it would have cost to have put in a 12-inch lining.

This method of lining a tunnel for protection is equally applicable in tunnels lined with brick, which are disintegrating, and in concrete lined tunnels which are showing signs of wear and tear.

In a great deal of work carried out by the Illinois Central Railroad in the South, it has been found that wood borers, such as the teredo, will eat away piling on the inside. In seeking some method to protect this piling, the cement gun was suggested. It is necessary to protect only the portion of the pile which remains out of the ground, as these wood borers will not attack below ground level. These piles were driven into place with a 3000-pound hammer, with no injury to the gunite coating, and to the author's knowledge have been in place a matter of four years. In

a recent letter, the bridge engineer of the Illinois Central Railroad stated that a minute examination was made of these piles, and that the wood borers had not succeeded in penetrating the gunite coating.

Mine shaft lining is another field where the cement gun is used, especially where the shaft is timber lined, and it is necessary to waterproof and fireproof it. No doubt some engineers in the audience can remember the Cherry Mine disaster in Southern Illinois, in which some one hundred miners burned to death. It was after this disaster that Illinois passed legislation that all mines which had timber lined shafts must be made fireproof.

The best and most economical method is to install a layer of reinforced wire mesh, nailed direct to the timbers, and shoot on about 2 or 2½ inches of gunite. This has proven very successful, and I might say that the firm with which I am connected is carrying out 10 contracts on these mines, and is under contract for 4 more.

The cement gun has had many failures, and will continue to have, when inexperienced people try to use it on work that requires skill and technical knowledge.

I hope that the few illustrations incorporated in this paper will serve to show the advantages that may be gained through the merits of this machine and its products, by which a saving can be effected which will be impossible otherwise. By that, I do not mean to imply that the cement gun affords a cheap method of construction. It is quite an expensive plant, involving machinery that runs into thousands of dollars. Of course, there are a lot of instances in construction work in which it has proven cheaper than any other method; but, on the other hand, in some of its operations the work is very expensive. It takes trained men to get results. No engineer or architect would place a difficult piece of foundation work in the hands of a plastering contractor. It is the same with gunite, if you have any work to be done with the cement gun, consult someone who knows what a cement gun is; what it can do, and what it cannot do. There are many things it cannot do, and it is with these things that many engineers have failed and ultimately blamed the cement gun.

Many men have come into my office expecting that we would

quote them a price to stucco, say, one or two houses more cheaply than the work could be done by hand. We, as engineers, can readily see that this is impossible, as the initial cost of getting machinery on the job is perhaps greater than the whole job is worth. It is the aggregate on such work as this that brings the unit cost down. I personally know of one instance where we were given the contract to erect 56 houses for the Government, and the ultimate cost for a two-inch wall and roofs ran about 80 cents per square yard. No fixed cost can be quoted. Different conditions make different costs.

The author has devoted many years to construction work by cement gun methods and the firm with which he is connected has successfully performed many jobs that have been considered impossible. The cement gun has many characteristics of its own, and to get good results you must get experienced men to do the work. Different kinds of work require different methods which are learned only by experience.

DISCUSSION

PROF. HORACE R. THAYER:* Do I understand that gunite is put on girders without any reinforcement whatever?

MR. ARTHUR J. WHITE: In very few instances can you coat steel girders without any reinforcement. I believe the only cases where gunite can be used without reinforcement are such as the one I mentioned in the paper; that is, where it is put on rough porous tile. We would not advocate any work being done without using steel reinforcement to take up temperature stresses.

MR. J. R. CLINE:† What are the proportions of sand and cement used in gunite?

MR. ARTHUR J. WHITE: That all depends on the class of work you are doing. We generally use about a one to three mix for ordinary work. When you have a very delicate waterproofing job, it is advisable to use a little stronger mixture. In the one to three and one-half the ultimate mix is about one to three. You lose about ten per cent. on the rebound. Of course, your rebound is gotten largely by the grade of sand used on the job.

MR. P. J. FREEMAN:‡ How about the use of gunite in tanks, etc.?

MR. ARTHUR J. WHITE: It has been very successful, lining both inside and outside of steel tanks. As a matter of fact, large tanks have been constructed with the cement gun instead of using poured concrete.

MR. P. J. FREEMAN: Do you do such work, for instance, as lining a railroad tunnel that requires overhead lining, say, two inches thick?

*Associate Professor of Structural Design, Carnegie Institute of Technology, Pittsburgh.

†Practice Man, Universal Portland Cement Co., Pittsburgh.

‡Testing Engineer, Pittsburgh Testing Laboratory, Pittsburgh.

Mr. Arthur J. White: Yes, it has been done very successfully. Sealing any rock cut with the cement gun is very successful. This is another instance where reinforcement has to be used. Reinforcing is put over the rock cut and fastened to the rock by drilling holes and driving steel pins to which the reinforcing mesh is attached. Then gunite is shot on to it. This prevents any frost effect acting behind the rock and loosening it and causing slides.

Mr. A. P. Krepp:* How about waterproofing a job that has a seepage coming through? We installed some electric furnaces where it was necessary to put in a pit to take the travel of a counterweight. We struck a lot of springs and the pit was continually filling with water. We had to keep it pumped out and we considered using some such method as the cement gun. I understand you have to use reinforcing with that.

Mr. Arthur J. White: It is advisable, especially where you have water coming in under pressure.

Mr. A. P. Krepp: It is only pressure coming from the soil surface seepage.

Mr. Arthur J. White: I would like Mr. Hoerr, Chief Engineer of the National Tube Company, to answer that question.

Mr. A. L. Hoerr:† We have an old pump house which was discontinued perhaps ten years ago and the wall had become very badly cracked. We deepened that pit about four feet, putting the bottom of the pit quite a few feet below the river level. We drilled the wall with small holes and into those holes we drove pins of steel to which triangular mesh was fastened. Then gunite was shot all over the walls of this pit. Very shortly after this was completed, the river came up quite a distance above the floor level and we saw no signs of any leakage or seepage. We are hoping very much much that it will prove to be a satisfactory job.

*Mechanical Engineer, Universal Steel Co, Bridgeville, Pa.

†Chief Engineer, National Tube Co., McKeesport, Pa.

The matter of price on that job was not even considered because there was no other way to solve the problem, at any reasonable cost. We had either to coat this with gunite or tear the whole thing out and start over again, which would cost many thousands of dollars. We hope that the entire pit was made water tight.

We have also used the cement gun in a great variety of other work—lining coal bunkers and ash bunkers, in some building construction, etc. The first job we did was for the floor system of an out-door, overhead coal room. That has been down two winters and is most satisfactory. My thought of the cement gun work would be that it is not often a matter of figuring whether it is the cheapest construction, because frequently it is the only construction that can be used, since the coating can be applied to horizontal and to vertical surfaces, or to any angle between the two. As Mr. White says, you must have reinforcing steel unless you are going to shoot on to an absorbent tile which has grooves for holding the cement.

Mr. A. P. Krepp: In our case, where we have this water continually seeping in and we have to pump it out, say, every 24 hours, I think the pit is probably 18 feet long and 10 feet wide, and it is at a lower level than the other part of the machine. It is an electric furnace with a tilting apparatus directly under the furnace and it has this pit to take care of the counterweight. There is a creek near, and there is a good bit of surface water coming in. We have water present all the time. In applying gunite, will that water seeping in interfere with the application?

Mr. Arthur J. White: If the water is not under pressure, the cement gun, I believe, is the only solution to dry out your pit.

Mr. A. P. Krepp: There is seepage coming in all the time from the surface and from the creek near by.

Mr. Arthur J. White: A couple of years ago we lined the inside of a railroad tunnel which was brick lined. We had a great number of wet spots which were easily overcome by putting in bleeders, segregating the water at one central point, and

finally sealing the bleeder up; but there was one place in this tunnel, an area of about 20 by 30 feet, in which we drilled 250 holes to find the seat of the spring, and, when we found the right one, the pressure was so great that the water came out with such force that it hit the other side of the tunnel. Once we found the seat of the trouble, of course, it was an easy matter to seal it up tight.

Another instance which comes to my mind is a well the American Bridge Company had in Chicago. This well was 25 to 30 feet deep and about 25 feet in diameter. The water was entering in so many places that it seemed impossible to get any cement to stay on the walls and set. We put a gun on the job and eventually sealed it up tight. This was a job where costs did not count; it was a case of getting it dry irrespective of costs. I will try to explain how this was done.

Centrifugal pumps were installed to keep down the water. We then drove railroad spikes into the rock, and to these we fastened a light triangular mesh. We set the gun in position and went over the whole area at once. Perhaps 95 per cent. fell off, but the other five per cent. stuck. This completed one day's work. The next day we repeated the previous day's performance and we got another five per cent. to stick. This performance was repeated until we had limited the seepage places to certain points. We then mixed sand, cement, and soda with boiling water and applied the mixture by hand to the points where the water was flowing. This mixture will set almost instantly. Eventually, by this method, the pit was made absolutely dry. It is another instance, as Mr. Hoerr stated, where the job was expensive but was the only remedy, under the circumstances.

Mr. A. E. Blake:* Are there any limiting meshes?

Mr. Arthur J. White: Yes, we generally put the cement and sand mixture through a ⅜-inch screen before it goes into the gun.

Mr. A. E. Blake: That is almost coarse enough for gravel.

*Sales Engineer, Surface Combustion Co., Pittsburgh.

MR. ARTHUR J. WHITE: Yes, I believe ⅜-inch granolithic chippings have been used in the way of a fine aggregate. Ordinarily, we do not advocate anything but sand and cement.

MR. A. E. BLAKE: You have a small portable outfit?

MR. ARTHUR J. WHITE: That is a cement gun, alone. A complete cement gun outfit is rather a big thing. You have to have an air compressor capable of delivering 200 cubic feet of free air per minute, actual delivery.

MR. A. P. KREPP: Do you calculate the amount of pressure you are going to use on every job? Taking the job I am speaking of, do you think it would be necessary to put in reinforcing steel, or would it be sufficient to put in triangular mesh or poultry wire?

MR. ARTHUR J. WHITE: We would certainly advocate using triangular mesh. Poultry wire has no reinforcing value. If you are incasing small steel members where it is difficult to bend heavy steel around, then poultry mesh can be used. The American Steel & Wire Company's triangular mesh is not much more expensive and insures a much better job. In this mesh you have something that will take up the temperature stresses while the poultry mesh will not.

MR. C. N. HAGGART:* What is the approximate cost of getting an outfit on the job, including the compressor and gun?

MR. ARTHUR J. WHITE: That all depends on the class of work you are going to do and the amount of equipment needed. If the full equipment is needed, you have a cement gun, which weighs about a thousand pounds, and a fuel-oil driven, self-contained air compressor which weighs approximately six tons. Apart from this, you have the hoses needed, and other miscellaneous requisites which make a very heavy outfit.

MR. A. P. KREPP: If there is a compressed air supply in the plant, could you use that, and would you allow for that in the contract?

*Contracting Engineer, Pittsburgh.

Mr. Arthur J. White: Yes, we would; as compressed air is a very expensive item.

Mr. C. N. Haggart: Is a gunite roof waterproof?

Mr. Arthur J. White: To a certain extent, yes. Gunite, in itself, is waterproof; but on slabs of large area you are bound to have shrinkage cracks in which you are bound to have some seepage. I can cite you many instances, however, where gunite roofs have been been put on without any waterproof covering whatever. The roofs I mention are mostly on such buildings as forge shops, foundries, etc., where a little seepage does not do any harm.

Mr. J. A. McEwen:* What would you recommend for waterproofing?

Mr. Arthur J. White: Do you mean in the way of composition roofing, or do you mean any patented liquid mixed with the concrete? A composition roof can be put on the gunite roof just the same as on any other roof, such as asbestos, etc.

We completed a contract a couple of years ago at the James McKay Company's plant, McKees Rocks, Pa., where we laid a 1¾-inch roof on eight-foot purlins; and, up to the present time, there is no waterproof covering over it. This is over a forge shop where a little seepage is not doing any harm. I might mention the fact that three of us jumped on this roof without doing any damage whatever.

Mr. P. J. Freeman: What mesh did you use?

Mr. Arthur J. White: The American Steel & Wire Company's 0.068 triangular mesh. Wooden forms were wedged tight up against the top flange of the purlin.

Mr. A. P. Krepp: Have you had any success in covering the roof and sides of coal mines where oxygen has affected the slate?

*Manager, Pittsburgh Bridge & Iron Works, Pittsburgh.

Mr. Arthur J. White: Yes, this is done to a great extent in coal mines, and, personally, I believe the cement gun is an equipment that every coal mine should have. This is an instance where it pays the owner to have his own gun and seal up the rock and slate as he drives his entries.

Mr. A. P. Krepp: Is there a portable machine that could be taken from one part of the mine to another?

Mr. Arthur J. White: Yes, there is a special portable outfit made for mine work.

Mr. A. P. Krepp: What is the approximate cost of one of these guns?

Mr. Arthur J. White: I could not tell you. The gun costs somewhere around $1500, but I do not have any idea what the compressor would cost.

Mr. Willis Leriche:* The mine-type portable compressor sells for $2700.

Mr. A. P. Krepp: Does your company hold the patents on this cement gun?

Mr. Arthur J. White: No, we do not hold any patents on the gun. We do hold some patents on the different methods of construction and all we do is construction work with the cement gun. We do not touch any general contract work. Anybody can buy a cement gun and enter this field. The only patents for the manufacture of the cement gun are held by the Traylor Engineering & Manufacturing Company of Allentown, Pa.

Mr. Paul Whitman:† Have you any experience in lining self-supporting steel stacks? It would seem to be an ideal apparatus for that.

*District Manager, Cement Gun Company, Inc., Kansas City, Mo.

†Engineer, Riter-Conley Co., Pittsburgh.

Mr. Arthur J. White: Yes, it is. The Ford Motor Company, in Detroit, has six self-supporting stacks on top of its power-house. These were lined by the cement gun, for the top 50 feet. From the base up to within 50 feet of the top, it was, of course, lined with fire-brick. These stacks are 262 feet high.

Mr. Paul Whitman: The surface of the steel plate on the inside diameter of the stack corrodes very rapidly due to the sulphur and heat in the escaping gases. Would not gunite, which adheres so closely to the steel, largely prevent this corrosion?

Mr. Arthur J. White: Without a doubt it will stop corrosion. You have a better bond to the steel than could be obtained by carrying the fire-brick lining right up to the top of the stack. Gunite will stop corrosion of the steel on the inside of coal bunkers where the abrasive action is very great. It has also been used very successfully for incasing the steelwork of bridges and viaducts where the locomotive gases disintegrate the steel very rapidly.

Mr. Paul Whitman: In order to reduce the cost of the brickwork with which steel stacks are ordinarily lined, it is common practice to support the brick lining by steel rings riveted at intervals to the steel shell. The weight of this brickwork is then carried by the steel shell of the stack through the successive rings to the foundation. The additional stress thereby produced in the steel must be taken care of by increasing the thickness of the steel plate and the number of rivets in the circular seams—particularly in the lower rings of the stack—as the effect is cumulative as we approach the base. As gunite would probably weigh only about one-third as much as the replaced brickwork, it would seem that its use, particularly in the case of high stacks, would permit us to effect a considerable saving in the amount of steel required, and a consequent reduction in the cost of the completed structure.

Mr. Arthur J. White: The average weight of gunite is about 25 pounds per square foot for the two-inch slab, but I

would not advocate the lining of the inside of stacks where the temperature at the base is over 1000 degrees F. In lining the top 50 feet, as previously mentioned, on the Ford Motor Company's job, this is quite all right; but, where you have temperatures running very high, especially stacks with forced draft, it is my opinion that the heat is too great to put in concrete.

Mr. A. P. Krepp: What is the possibility of using refractory material on the side of a wall to stand high temperature?

Mr. Arthur J. White: I do not know whether it has been tried, and I would not like to commit myself until it has been tested. I believe Mr. Leriche is at this time carrying out some tests of this kind in Chicago.

Mr. Willis Leriche: Fire tests of gunite panels, which will give valuable data regarding the properties of gunite under high temperatures, are to be made within a month by the Underwriters Laboratories at Chicago. However, enough tests have been made, so far, to demonstrate that gunite withstands the disintegrating action of heat better than ordinary concrete. This is, no doubt, due to its greater density.

In the case of the self-supporting, reinforced gunite stack recently built around a disintegrated steel stack at the plant of the Illinois Steel Company, gunite was applied directly against the hot plates. At the base, the temperature was such that water boiled when thrown on the plates. In spite of these unusual conditions the gunite is perfectly sound. The only precaution taken was to keep the work thoroughly wetted down for a period of two weeks.

Where temperatures obtain much in excess of those indicated above, the gunite method can still be successfully employed, by first placing around the hot steel, a layer of insulating material of either cork or asbestos.

Mr. White has also referred to the use of gunite to prevent corrosion on the inside of steel stacks. I have been unable to learn definitely whether or not the greatest corrosion takes place on the inside or outside of a stack which is lined with fire-brick.

However, many of the failures have occurred at the rivet joints in the upper portion of the stack, which would indicate that condensation takes place due to the cooling of the gases. This condensation is most likely sulphurous acid which collects in the joints and is responsible for the corrosive action.

A gunite lining placed simultaneously with the fire-brick lining would resist the weak acids formed, and certainly increase the life of the stack. Recent tests have shown that gunite will not be destroyed by a 10 per cent. solution of sulphuric acid.

Where the steel is subject to high temperatures, fire-clay, which is easily applied with the cement gun, would probably give better service. The lining of ladles and other containers of molten metal is now being successfully applied with the gun. Other examples in the use of the cement gun for placing refractory materials on heated surfaces where temperatures exceed 3000 degrees F. can be found in the coking industry in the repair of door-jambs and the luting of coke-oven doors.

Mr. A. E. Blake: You should find out that you have the same coefficient of expansion as the steel, in that case.

Mr. J. P. Toler:* What temperatures do you expect in the flues?

Mr Willis Leriche: Temperatures running up to 1200 degrees F.

Mr. J. P. Toler: In that case it would be impossible to set the clay.

Mr. A. P. Krepp: You cannot get clay to set up tight. In building a furnace you do not have a very thick layer. The brick is set in a thin grout of fire-clay and that takes care of the expansion and also causes a bond. As I see it, it would hardly be possible to use fire-clay and make a refractory, on account of it not setting up.

*Chief Engineer, Crescent Portland Cement Co., New Castle, Pa.

Mr. Willis Leriche: They are using the cement gun for lining the inside of coke-ovens and ladles and they use fire-clay for that.

Mr. A. P. Krepp: Yes, but that is where you can depend on the stuff staying up. Gravity would not pull it away. You can hold it until it is set.

Mr. A. L. Hoerr: I know of a number of cases where stacks have been destroyed by corrosion from the inside. Where the stack temperatures are low there seems to be a condensation which with the sulphur gases deposits in the joints or seams of the stack, and in at least half a dozen cases the stacks were rescued from falling, just in time, and those stacks were all lined with fire-brick. The upper third of the stack had such a low temperature that not only the moisture from the rain, but actual condensation inside the stack got through the fire-brick and destroyed the stack. In such stacks, a cement lining would be entirely adequate and much superior to fire-brick, because you would have a bond between the steel and the cement which you do not have with the brick.

Mr. Arthur J. White: I carried out some very interesting tests for the Champion Fire Brick Company, of Canton, N. C. This company had some wood-pulp digesters made of steel. The greatest trouble was from the boiling effects on the steel, especially in the sulphate process. The boiling action was wearing away the steel at a rate of about 1/32 inch per year. These experiments were carried out in a small digester. We lined the inside of this small digester more than four years ago and, up to the present, we have not heard of anything detrimental, and we have not had any complaint. I have every reason in the world to believe it was successful.

Mr. Paul Whitman: I would like to ask the author if he has ever had any experience with the use of gunite in lining agitators for oil refinery work. The customary practice in such work is to put a lining of sheet lead in the agitator to protect the steel from the action of the acid. Would it be possible to replace this expensive lead lining with gunite?

Mr. Arthur J. White: I do not think that anything of that kind has been done, up to the present; but, in view of the fact that tanks have been constructed of gunite, I do not see why it would not be successful. It has been successful in lining ammonia tanks.

Mr. A. P. Krepp: In your process you have a mixture of sand and cement. That makes it rather expensive, by using a good deal of cement.

Mr. Arthur J. White: No, because the strength and density you get reduce the section.

Mr. A. P. Krepp: Being able to get a denser section offsets the cost of a thicker wall where you would use gravel.

Mr. Arthur J. White: Yes, you are quite right. It has been proven that the three-inch gunite wall is as strong as a six-inch poured concrete wall.

Mr. J. P. Toler: Is there any demand for the use of gunite in the construction of small dwellings?

Mr. Arthur J. White: No, I do not think there is. I do not think it would pay unless you had quite a number of houses to build—say fifty to one hundred. The initial cost of getting your machinery on the ground is too great where you have only one or two houses to do, and the work can be done by cheaper methods. At the present time the cement gun is being used on quite a housing proposition at Flint, Mich. On this job, I believe, there are about sixty to seventy-five houses.

Mr. A. P. Krepp: Does a cement gun leave a stucco finish?

Mr Arthur J. White: Yes, although that greatly depends on the grade of sand you use.

Mr. Earle V. Braden:* Is the maintenance of a gun and hose expensive?

*Engineer, Pittsburgh, Chartiers and Youghiogheny R. R., and Chartiers Southern R. R., Pittsburgh.

MR. ARTHUR J. WHITE: It is very expensive. The hose is specially manufactured of pure rubber, strongly reinforced with canvas, and at the present time it costs about double what it did before the war. The depreciation on the gun itself is not very great; occasionally gaskets or some small incidental fittings are required.

MR. P. J. FREEMAN: Have you ever used any slag sand?

MR. ARTHUR J. WHITE: Yes, to a considerable extent, especially where weight is an item; as, in using slag, your weight per square foot is cut down a matter of two or three pounds.

MR. P. J. FREEMAN: Have you used granulated slag?

MR. ARTHUR J. WHITE: No, we have not.

MR. A. P. KREPP: How do you take care of the bonding of your gunite to old work?

MR. ARTHUR J. WHITE: Simply have a clean surface, and depend on the force with which it is applied.

MR. A. P. KREPP: Do you wire brush it?

MR. ARTHUR J. WHITE: Yes, in some instances, but we generally find we can get a perfectly clean surface by sand-blasting it, in which the cement gun is a very satisfactory sand-blast machine.

MR. A. P. KREPP: You can use the sand-blast with the cement gun, can you?

MR. ARTHUR J. WHITE: Yes.

MR. A. P. KREPP: You have a nozzle to let the sand go through without the cement, have you?

MR. ARTHUR J. WHITE: There is an especially manufactured sand-blast nozzle. When using the cement gun as a sand-blasting machine, we simply put sand into the gun and do not mix any cement with it.

MR. C. T. DAY:* What experience have you had with alkaline substances? I should imagine that, on account of the density

*Detailer, American Bridge Co., Pittsburgh.

of gunite, you would not have the usual trouble of corrosion with alkalis.

Mr. Arthur J. White: Would bleaching tanks in a paper-mill cover your question? I am not a chemical engineer, but we have done quite a lot of work in and around paper-mills and we have constructed electrolytic tanks in which alkali is used, and they have been very successful.

A particular job I have in mind was done for the Anaconda Copper Company. In all previous construction of these electrolytic tanks, this company made them out of poured concrete. Due to the effects of the alkali on the surface of these poured concrete tanks, it would not stand up and it powdered very quickly.

Mr. C. T. Day: That is practically the result you get in alkali soil; concrete is attacked in that way.

Mr. Arthur J. White: We have also successfully lined bleaching tanks in pulp mills.

Mr. A. E. Blake: Was that electrolytic bleach in a paper-mill?

Mr. Arthur J. White: Yes.

Mr. A. P. Krepp: Does your company guarantee your work, if you are waterproofing a job, for instance?

Mr. Arthur J. White: What sort of a guarantee do you want; that it will not leak any more? I do not know what the guarantee would cover or what it could be. We simply do our best and that is all we can do.

Mr. J. O. Jackson:* Has the cement gun ever been used in laying dust-proof coatings on concrete floors?

Mr. Arthur J. White: It has been used, but I think there are a great many better things on the market. The cement gun has been more used for repairing floors than it has been for laying dust-proof coatings.

*Assistant Superintendent, Pittsburgh-Des Moines Steel Co., Coraopolis, Pa.

SURFACE COMBUSTION

By A. E. Blake*

Advance copy of a chapter in R. F. Bacon and W. A. Hamor's "American Fuels" to be published by the McGraw-Hill Book Co., 239 W. 39th St., New York. Presented before the Engineers' Society of Western Pennsylvania with the permission of Messrs. Bacon and Hamor, of the Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh.

Surface combustion† is the term applied to the process long recognized as ideal for the oxidation of fuel gases. The name originated in England, where it was applied to the catalytic action of metals, such as platinum and silver and their group members, upon homogeneous explosive mixtures of air and fuel gases, especially when the latter contain free hydrogen. At first, the catalysis was studied at temperatures *below* the ignition point of a mixture. It was observed that as the temperature of the metal was increased, the reaction was accelerated positively in practically all cases. The metal was used in the massive form instead of in the spongy state.

Bone‡, McCourt, and others, noticed that the speed of reaction becomes very great when the metal is at a temperature sufficiently high to emit light; also that at such temperatures, non-metallic substances—such as burnt clay, porcelain chips, and other ceramic material—begin to exert an accelerating influence which increases with the increase in temperature of the solid. Whatever may be the influence of the solid at low temperatures, the influence of any solid in granular, porous condition was found to be more and more nearly equal to that of any other, as the intensity of light from the solids was increased. This gave rise to the belief that the influence of sufficiently refractory material would be

*Sales Engineer, Surface Combustion Co., Pittsburgh.

†Process and apparatus covered by United States letters patent and applications for United States letters patent.

‡William A. Bone, D. S., F. R. S. Fuel and Metallurgical Department, University of Leeds, England.

exceedingly great at temperatures *above* the ignition point, particularly when strongly incandescent. The belief was quickly confirmed. It was found that gaseous reactions could be carried out at rates several million times as great as the ordinary rates of combustion. Efforts were at once made to use the discovery in heating practice. The work naturally led to the use of homogeneous mixtures which contained air and gas in quantitative proportions for complete reaction. Such mixtures are termed "perfect mixtures," and the reaction, "perfect combustion."

Due to the fact that a perfect mixture is really a true solution of gases in which the constituents which are to react are in a state of intimate mutual collision, the time required for reaction is what may be termed of molecular dimensions, referring to the time intervals between collisions. Normally, reaction should begin whenever impacts are of sufficient violence to disrupt the molecules; this is the probable status at ignition temperature. Projection of the gases against large effective areas of incandescent solids, however, subjects them to the ionizing influence of the ultra-violet or short-wave light*, causes increased sensitiveness to molecular impact, and thus promotes greater speed of reaction. Under the conditions stated, reaction is flameless and invisible. In describing the process Bone and his associates made use of the term "flameless incandescent surface cumbustion."

Prior to the work of Bone, Lucke† employed granular refractory material to assist in combustion when using similar air-gas mixtures. He adopted the term "surface combustion," but in a different sense from that taken by the English workers. A supply of air-gas mixture, in such proportions as to support combustion, issuing from an orifice at a rate of flow exceeding the speed at which combustion is propagated through the mixture, will expand, and the linear speed of all parts of the stream will decrease. At some zone surrounding the orifice, the flow speed will equal that at which combustion is propagated. At this zone, Lucke conceived that combustion would begin, and that the reac-

*P. Lenard, Annalen der Physik. 1900. ser. 4, v. 1, p. 498; ser. 4, v. 3, p. 298.

†Charles E. Lucke, Ph. D. Head of Mechanical Engineering Department, Columbia University.

tion would be complete within a very short distance—hence the term "flame cap," or "surface of combustion." Owing to difficulties experienced in regulation, steady maintenance of the flame cap was impossible and use was made of granular refractory material as a baffle and container for the surface of combustion.

Perfect combustion is the usual aim and attainment in the process being described, and, for that reason, the above term has become synonymous with surface combustion. The advantages to be obtained from perfect combustion are self-evident and of great importance.

The gas is completely consumed and the total available energy is released for service.

Since neither air nor gas is in excess, the volume in which the reaction takes place is minimum, and the concentration of energy, therefore, is maximum. In other words, the highest reaction temperature is attained for the fuel being used. The greatest possible difference will exist between the temperature of the products of combustion and the material which it is desired to heat, in which case the rate of heat transfer will be the greatest. By shortening the time of heating, in many classes of work, much heat is saved which would otherwise be lost through the furnace walls in an extended period of firing.

Because of the fact that combustion takes place with no delay, the heat carried by the products of combustion will have the longest possible time to give up heat before leaving the furnace. By way of contrast, attention is called to ordinary methods of firing in which combustion is not immediate but takes place with the formation of flame, due to the lack of complete mixing of the air and gas which are usually permitted to enter the furnace in strata. In such a case the rate of combustion will depend upon the rate at which the air and gas diffuse one into the other, bringing within actual range of one another the molecules which are to react. Such a flame may extend the whole distance between the burner and the flue. The products of combustion set free in that portion of the flame near the flue cannot have as long a period to remain within the furnace as those released at the beginning of the flame near the burner, therefore the possibilities for heat transfer are very much reduced.

With a small reaction zone, substituted for the flame commonly used, danger of injury to the work by contact with free oxygen, or with raw gas, is completely eliminated. The space required for this zone is very much less than the space which must be provided for the existence of a flame. Thus surface combustion permits the use of furnaces which have much less internal area, resulting in lower fuel requirements for maintaining the required temperature within a furnace.

Radiation effects secured by the maintenance of flame within a furnace are easily surpassed by the radiation effects secured with proper application of surface combustion, and with less deterioration of the furnace. Flame radiance is due chiefly to the incandescence of carbon particles freed by the early combustion of hydrogen, in the case of hydrocarbons. Under proper conditions, the carbon thus freed is oxidized, in turn, within a brief time. When the conditions are unfavorable, however, the carbon is not entirely consumed. This may be due to the lack of proper concentration of O_2, in which case the unconsumed carbon loses its heat and luminescence and appears as soot or smoke. This frequently obscures the interior of furnaces and prevents effective radiation to the work. With complete combustion, however, and very high luminosity, much injury to the furnace walls and roof may result; probably on account of the rapidly alternating oxidizing and reducing conditions imposed by the reacting gases in contact with the brick commonly used. When firing with a perfect mixture, the difficulties which have been mentioned do not constitute a limitation to the production of radiant energy. Combustion will be complete and nothing can obscure the furnace interior. Reacting gases cannot come in contact with the furnace walls and cause injury. With the proper use of refractory material in porous, granular form, it is possible to form sources of radiation which are capable of far greater intensity than that of any flame which could be produced. This is common surface combustion practice.

Since the nature and value of radiant energy are, evidently, not generally understood, it seems well to digress sufficiently to recall a few of the principal known facts and theories relating thereto. The atoms of any glowing solid possess enough vibra-

tory energy to induce wave motion in ether, thus causing production of light. The greater the amount of energy imparted to the solid, the more luminous it becomes; that is, the shorter are the wave-lengths generated in the ether. Regardless of wave-length, light waves travel with the speed of 10^{29} cm. per second. Compared with this speed, swiftly moving gases in a furnace are stationary.

The light of longer wave-length is of no particular benefit in the matter of energy transmission, but the shorter waves, particularly those which are responsible for the ultra-violet portion of the spectrum, are of vast importance. Generally speaking, the whiter the luminosity the larger the proportion of ultra-violet light produced. Light of short wave-length impinging upon solids, liquids, or gases sets the atoms or molecules in motion. The atoms of a solid are caused to vibrate more rapidly, thus evidencing increased temperature. It is in the form of radiant energy that heat reaches the earth from the sun, since there is no atmosphere known between the two bodies. The various chemical changes involved in plant growth are promoted by sun radiation. Concentration of such radiation by means of a lens serves to illustrate its power to generate heat in solid matter. The beam from a steriopticon lantern can be used to produce similar results.

Heat transfer from gas to solids may often be retarded by the existence of gaseous films at the surfaces of the solid, especially if the surface be not smooth. Langmuir*, has shown that such films exist upon the interior surfaces of exhausted incandescent-lamp bulbs. Whatever may be the extent of such influences, it is plain that light waves can penetrate such films with ease.

The use of air in excess of the amount actually required for complete combustion has been regarded as a necessary evil by those who have not made use of equipment such as will be described for the production of a perfect mixture. When employing ordinary equipment and obtaining delayed combustion, as evidenced by the existence of flame within the furnace, it is found necessary to permit the entry of excess air in amounts sufficient to prevent the flame from extending into the flue. It is a case of

*Irving Langmuir, Journal of the American Chemical Society. 1915. v. 37, pp. 1139–1167.

increasing the rate of a reaction by increasing the concentration of a component. In other words, excess air makes certain that the gas will be promptly overwhelmed and completely consumed be-

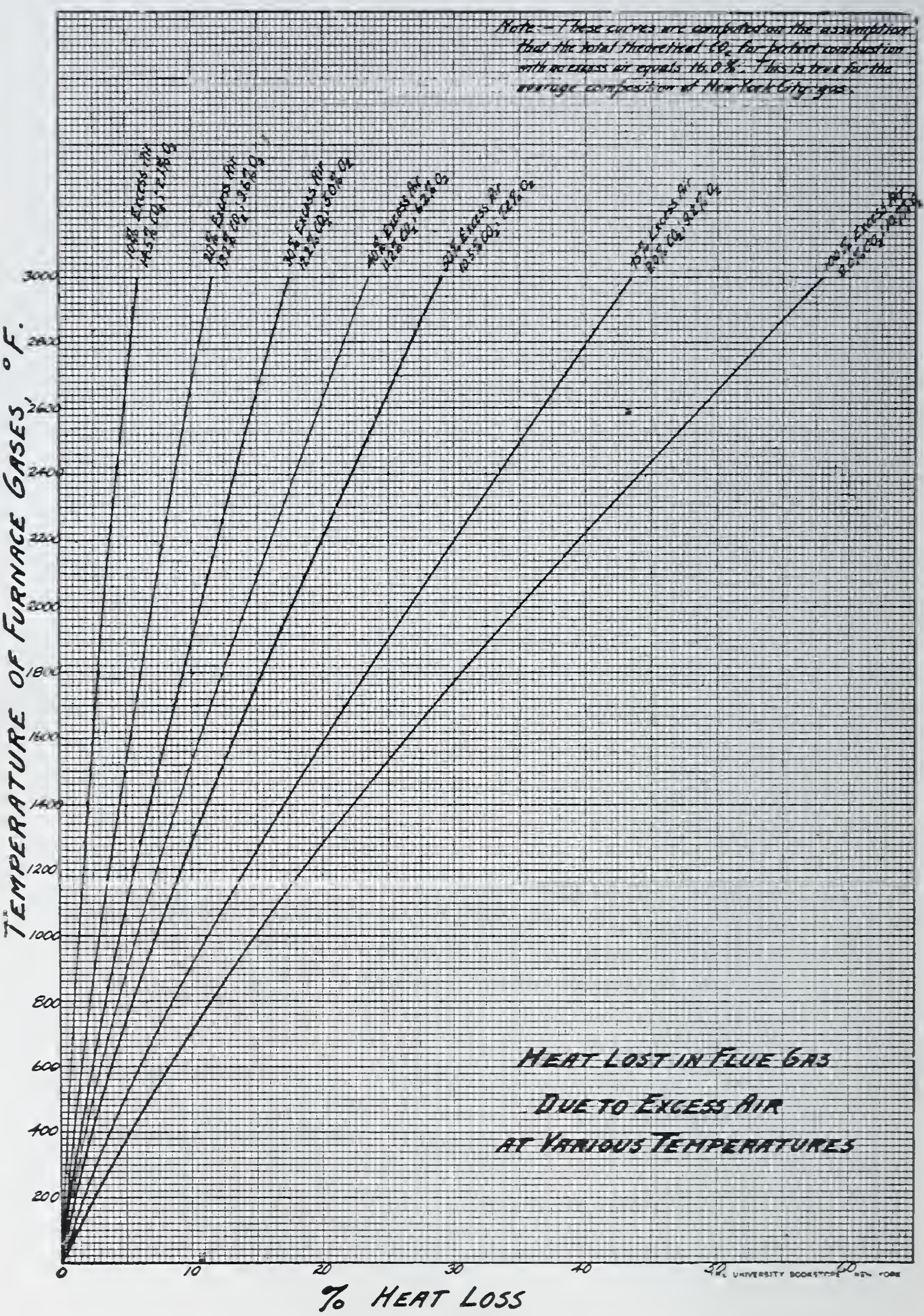

Fig. 1. Heat Lost in Flue-Gas Due to Excess Air at Various Temperatures.

fore leaving the furnace. In such cases, however, energy is absorbed by the non-reacting air in coming to the temperature of the gases entering the flue. The amounts of energy thus prevented from doing useful work within a furnace can be found by inspection of Fig. 1. An excess of 50 per cent. of air used with the gas mentioned, when operating at 2500 degrees F., will absorb 23.5 per cent. of the total heat liberated by the reaction.

FIG. 5

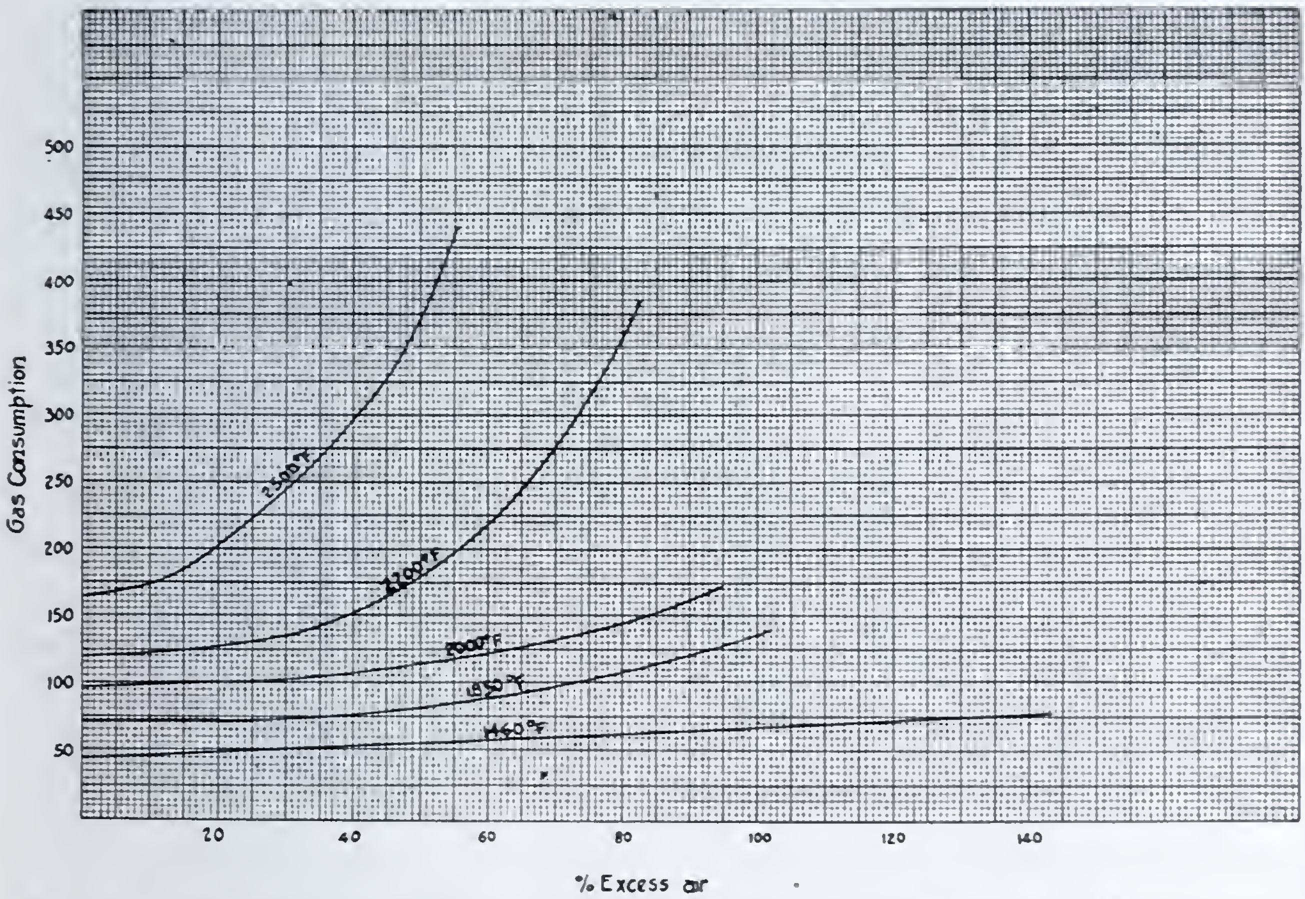

Fig. 2. Influence of Excess Air in Burning Homogeneous Mixtures of Air and Gas.

Fig. 2 shows the objection to the use of excess air in the surface combustion process. Homogeneous mixtures containing excess air cannot react as rapidly as perfect mixtures, because of the simple mechanical hindrance of inert molecules.

Neither can such mixtures react within a space as small as will suffice for a perfect mixture. The resultant reaction temperature is lowered; therefore, greater amounts of gas must be burned if it is desired to hold a given temperature in any case. A small surface combustion furnace was used in securing the data*. It will be noted that while holding the temperature of 2500 degrees

*Statement by O. Lellep, before American Gas Association. (Not yet published.)

F. with a perfect mixture, 163 cubic feet of gas per hour were required. While holding the same temperature with 40 per cent. excess air, 300 cubic feet per hour were required.

It is a well known fact that the theoretical reaction temperature of producer gas, without preheating, is about 1000 degrees F. lower than in the case of gases composed entirely of combustible matter. In consideration of the above evidence, and the fact that producer gas usually contains 60 per cent. of nitrogen, the reason is not difficult to see.

The detrimental effects of quantities of free oxygen within a furnace are too well known to require comment. It is considered so serious as to cause the use of vast quantities of excess gas in certain steel-mill operations, such as annealing, and in the heat-

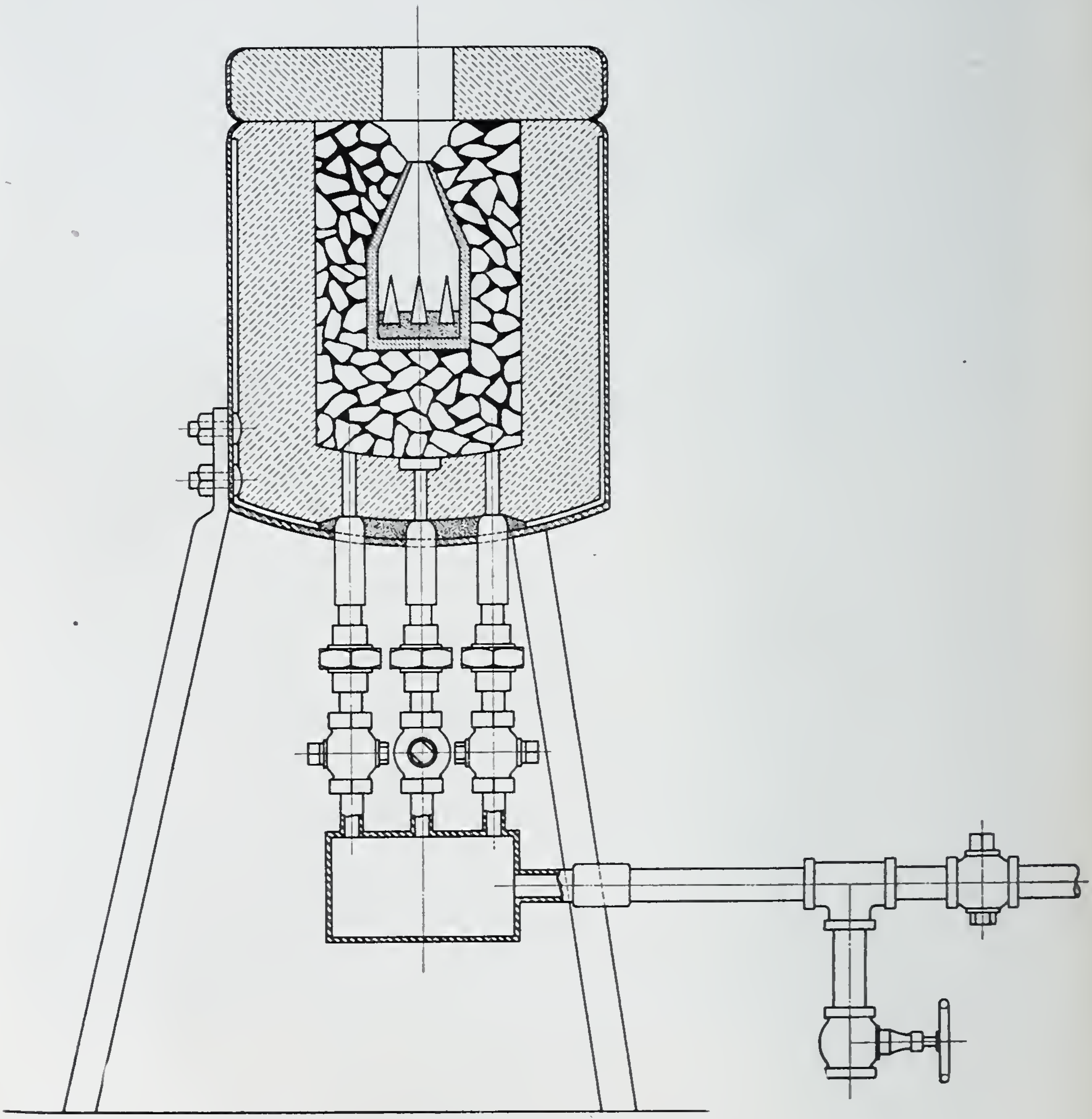

Fig. 3. Early Type of Surface Combustion Furnace.

ing of sheet bars, and sheets for rolling. It has recently been demonstrated that the use of a perfect mixture in such work results in a saving of about 60 per cent. of the amount of fuel customarily used.

Apparatus for the production and use of perfect mixtures is designed in accordance with the nature of the heating to be done and the gas to be used.

Fig. 3 shows an early type of surface combustion furnace which has again come into use for high-temperature fusion testing. Within the crucible, located as shown, pure alumina has been fused. Homogeneous air-gas mixture enters the refractory bed from below. At the zone where the flow is retarded to a rate equal to the rate of combustion propagation, reaction takes place. Above the zone, heat is absorbed from the products of combustion until the granular material has approximately the same temperature as the gases themselves.

The underfired refractory bed is unsuited for ordinary heating because of the difficulty in keeping the supply ports open.

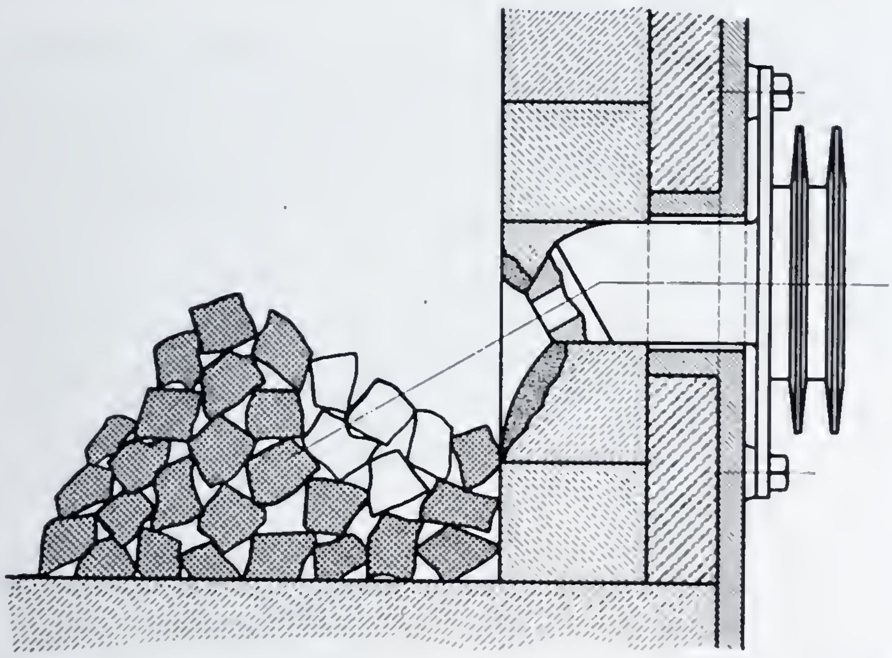

Fig. 4. Impact Type Burner Using Refractory Bed.

This difficulty has been overcome as shown in Fig. 4. This shows a delivery tube of special design in position to project a perfect mixture into a pocketed bed of refractory. The zone of combustion forms at the points within the bed at which the flow speed equals the rate at which combustion would propagate itself. The liberated products of combustion containing the energy set

free by the reaction find their way out of the bed and through the furnace. The bed becomes incandescent soon after starting, and the products of combustion will issue from it at the temperature of the solid material. At incandescence, the radiation is in position to increase the rate of combustion. Due to higher refractory qualities of the material composing the bed, it can be maintained at a state of incandescence greater than that of any flame which could be tolerated by the furnace lining. In low temperature work, it is customary to use this radiation indirectly rather than directly. The result is a very high degree of uniformity in temperature. The furnace interior is entirely free from flame or other obscurity. This application is in very extensive use, especially in heat treating, tinning, galvanizing, etc.

It is to be noted that the delivery tube, commonly referred to as the burner, is cemented tightly into the furnace wall. No air can enter except by the orifice, and no gases can escape at this point. The tube is designed to be self cooling. The orifice is

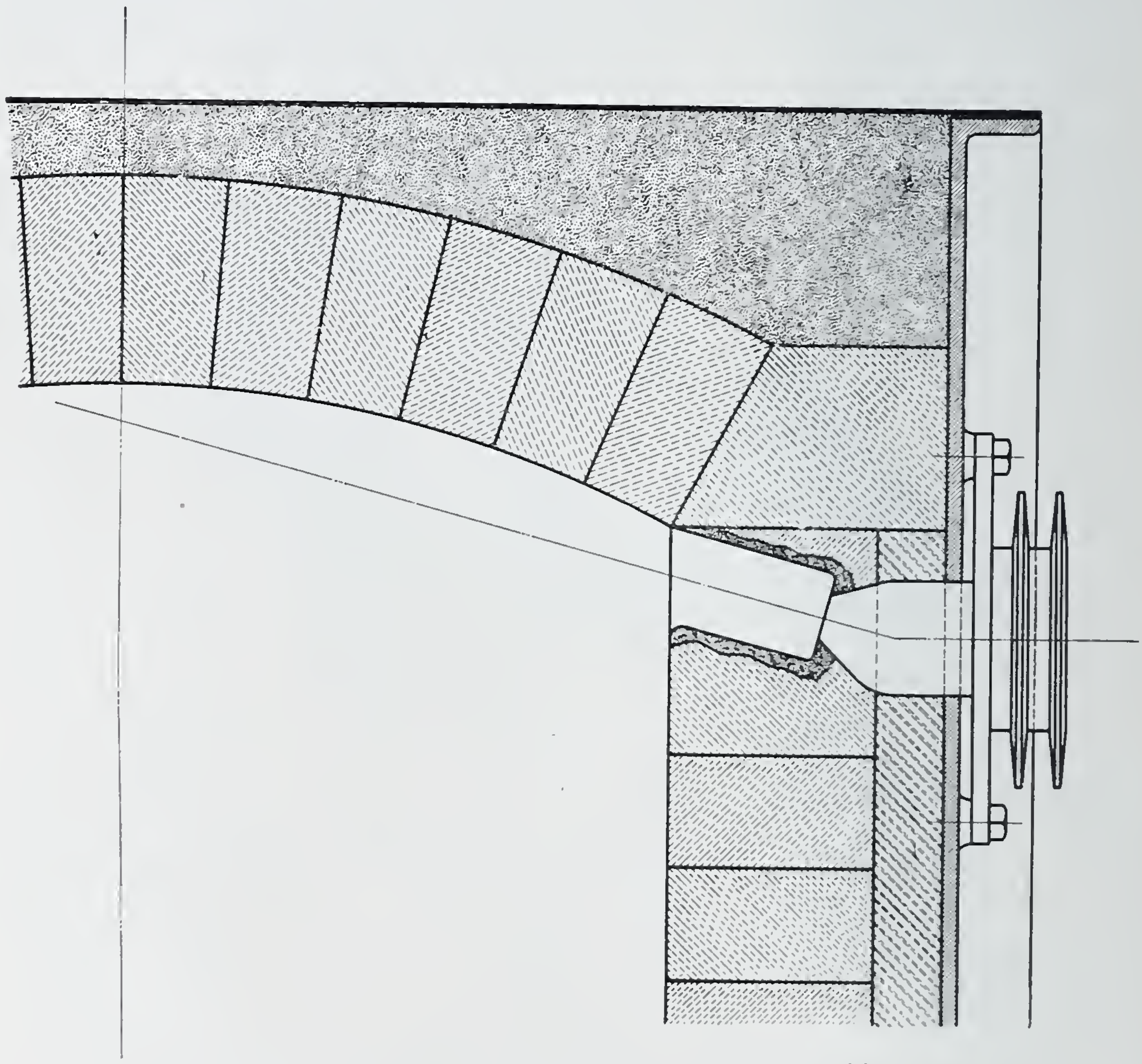

Fig. 5. Tunnel Burner of the Arch Type.

constricted, to accelerate the flow of mixture to a rate exceeding the speed of combustion propagation, as long as the flow pressure is greater than 0.2 inches, water-gage. Due to the positive pressure continually exerted within the furnace, the products of combustion are swept from the interior to the flues without the assistance of stack draft, which is actually detrimental in surface combustion practice.

Fig. 5 shows an application which has extensive use in glass melting, forging, shaping, welding, melting metals, sheet and pair heating, etc. Mixture is delivered from the metal nozzle to the base of a refractory cement-lined recess in the furnace wall. A portion of the expanding gases is retarded by the friction with the tunnel surface. Upon igniting, a small amount of the mixture burns within the tunnel, at its surface. The remainder burns outside, in the furnace chamber. The tunnel surface is rapidly heated to incandescence, however; and, when in that condition, combustion within the furnace chamber is no longer in evidence. Recalling the ionizing influence of radiant energy, and the speed at which it is transmitted, it is probable that combustion of the already potentially reactive mixture is complete within the tunnel. The location and direction of such tunnels will depend upon the numerous special factors involved in each case. Radiation effects are secured by permitting the products of combustion to sweep the roof or other portions of the furnace interior. Experience has shown to what extent this can be done with safety to the lining.

Several other types of burner are in use. Self-cooling, or air-cooled types are commonest, but occasionally water cooling is used.

The importance of uniformity of temperature in industrial furnace work is very often paramount. It is secured in the simplest manner. In general, burners of equal size, equally spaced, and equally supplied with perfect mixture, will solve the problem.

The factor of highest importance in the perfected surface combustion process is the production of perfect mixture, or of any desired mixture to produce essential conditions within furnaces. Fig. 6 shows one type of automatic proportioning and mixing device, attached to the manifold upon a furnace. It is called the low-pressure system.

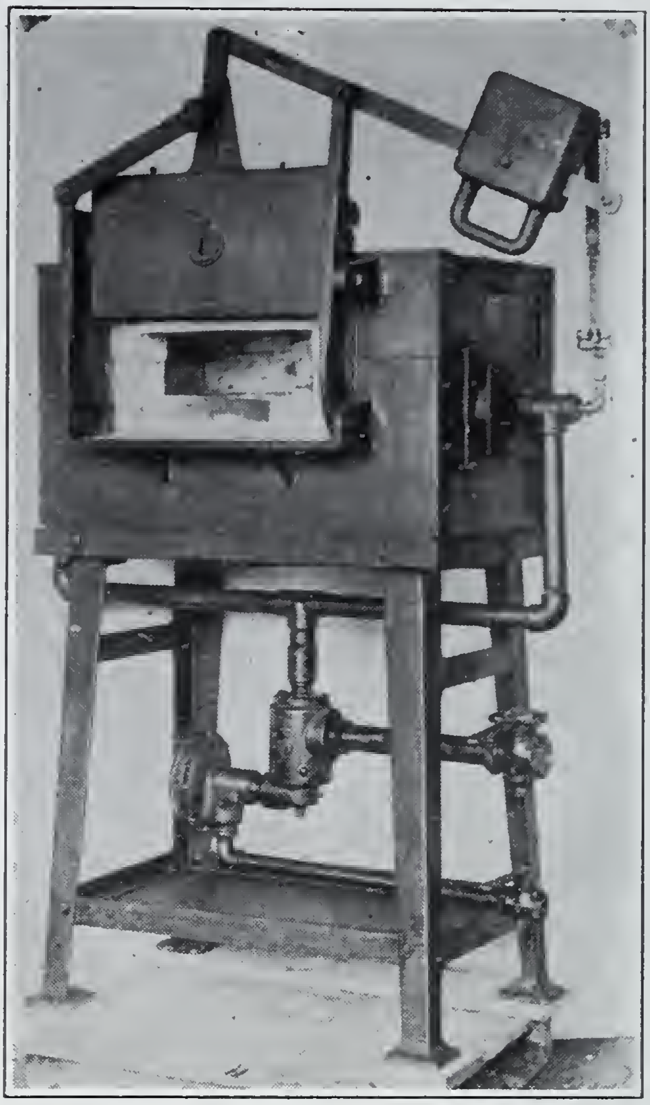

Fig. 6. Furnace with Low-Pressure Automatic Proportioner.

Air is supplied at a maximum pressure of about one pound per square inch, and governed in flow by the upper of the two cocks. Entering the chamber shown, it passes thence through a venturi tube to a manifold supplying the burners. A nozzle is located within the throat of the large tube. The nozzle can be adjusted with a screw-driver and secured by a lock-nut. The location of the nozzle in the large tube determines what proportion of air and gas will form the mixture. So long as the composition of the gas remains constant, no change in the position of the nozzle is necessary. Raising the nozzle increases the proportion of gas in the mixture. It is a simple matter to make the adjustment which will produce a perfect mixture. In operation, air creates suction upon the nozzle. Gas is drawn from a small governor which receives it at any pressure from one to about eight ounces. The function of the governor is the delivery of gas at constant atmospheric pressure at all times, regardless of the rate of flow. With the gas cock closed, and air flowing, reduced pressure is produced in the

governor and its connections, due to suction upon the nozzle. Atmospheric pressure will move the diaphragm inward and cause the entry port for gas to open fully. When the gas is turned on, the gas pressure within the governor will exceed atmospheric pressure for the moment and cause the diaphragm to move outward, drawing the slide-valve attached to it over the gas port, to a position where flow to the nozzle will continue at atmospheric pressure. Changing the air supply will automatically change the gas supply to insure constant proportion throughout the range of the device. During operation, the gas cock is never touched, but remains wide open. The convenience and economy of single valve control are obvious. Convenient for observation, a water-gage may be located upon the burner manifold, for the assistance of the operator in determining the rate of firing.

Fig. 7. Furnace with High-Pressure Automatic Proportioner.

Fig. 7 shows another device for automatically forming and supplying perfect mixture. It is called the high-pressure system. Suitable means are provided for supplying the gas at the requisite pressure; the pressure required varying with the gas used. One and one-half ounces per square inch is satisfactory for blast-furnace gas, while eight ounces or one pound will suffice for producer gas. Coke-oven gas can be used at from 3 to 10 pounds, and natural gas at from 20 to 40 pounds pressure. A modification of the apparatus permits the use of natural gas at 10 pounds, also.

In many cases both natural and artificial gases are available at the right pressure. When such is not the case, a

compressor is used. Gas is conducted under pressure to the apparatus. For proper control over the rate of firing, a valve and gage are provided, as shown. Gas is projected through a nozzle into the throat of a venturi entraining tube. Flow energy, or inertia of the gas, causes the entrainment of the air necessary for combustion through the ports shown. Proper selection of the gas nozzle and accompanying adjustment of the shutter by which the area of the air ports is varied, will enable the production of a perfect mixture, or of one which is rich or lean, as may be desired. When the desired setting has once been made, the proportion of air and gas will remain true and constant throughout the range of the apparatus, which is usually about four to one. The mixture becomes homogeneous at about the time it leaves the entraining tube to enter the manifold. This system does away with the necessity for air under pressure, and the consequent air piping, with all moving parts, such as a governor; also with any provision for draft for either the high- or the low-pressure system.

No decisive steps have been taken, as yet, in the matter of preheating air and gas either separately or combined. This is partly due to the lack of any difficulty in securing the highest temperatures which furnaces will withstand, and to the probable difficulty to be looked for in avoiding premature ignition. In several instances which have come to the notice of the writer, surface combustion furnaces have equalled in efficiency the fuel consumption of furnaces operating with preheated air, and have even made fuel savings of at least 40 per cent. The surface combustion process has won the support of numerous municipal gas companies and public service corporations, since it has enabled them to secure industrial consumers of gas and to hold them in the face of keen competition with other fuels as regards cost. This has been possible through the unsurpassed economy in the use of the gas.

The accompanying illustrations present certain examples of furnace engineering selected to give the reader some idea of the industrial application of surface combustion. Steam generation by this process has received little attention in this country thus far, but very remarkable results have been attained in England, and it is altogether probable that greater activity will occur in that line of work in the near future, in the United States.

A bibliography of the subject of surface combustion is appended.

Fig. 8. Surface Combustion Welding Furnace with Central Preheating Chamber. Lowell, Mass. City Gas Used as Fuel.

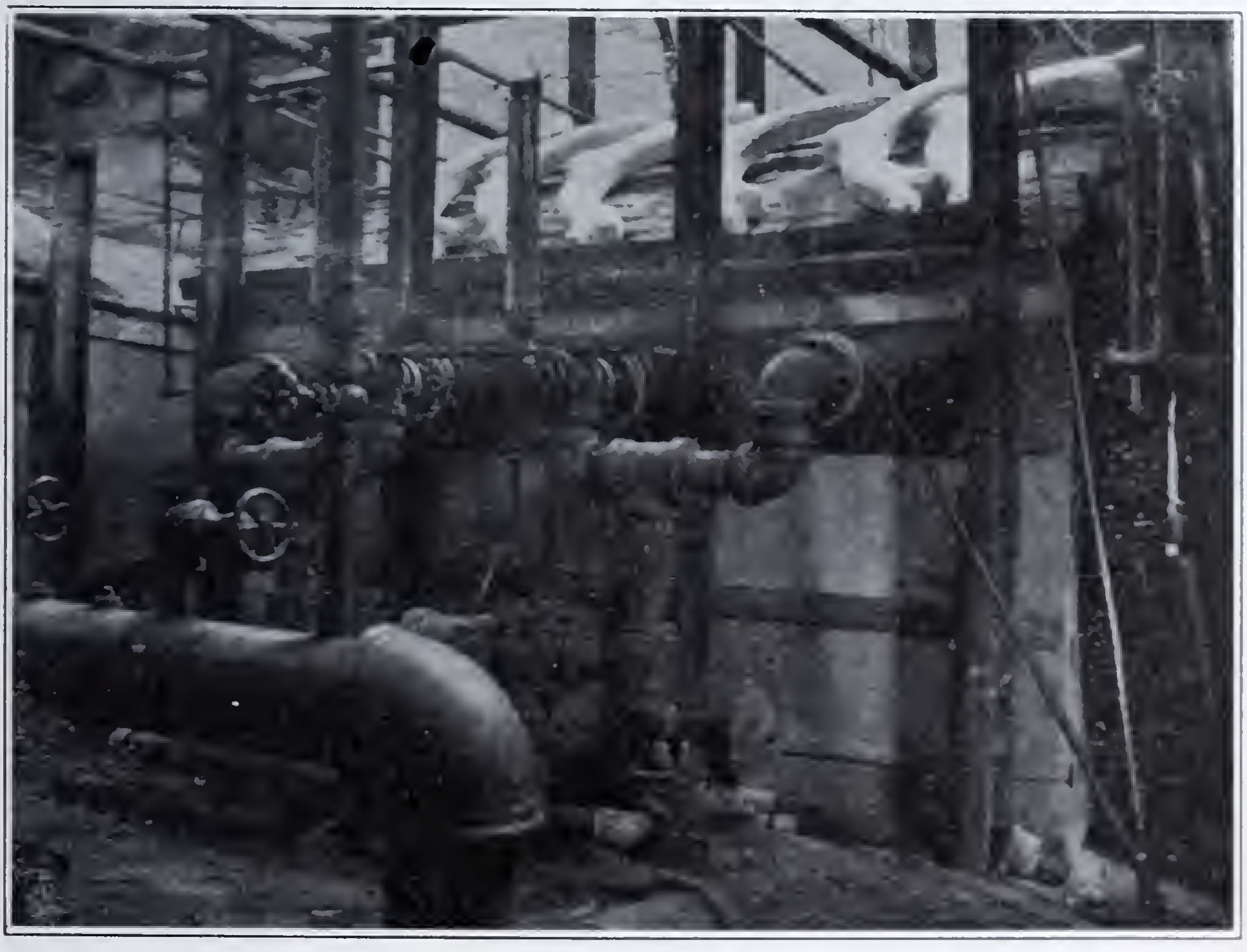

Fig. 9. Surface Combustion Day Tank for Melting Very Refractory Glass. Natural Gas Used as Fuel.

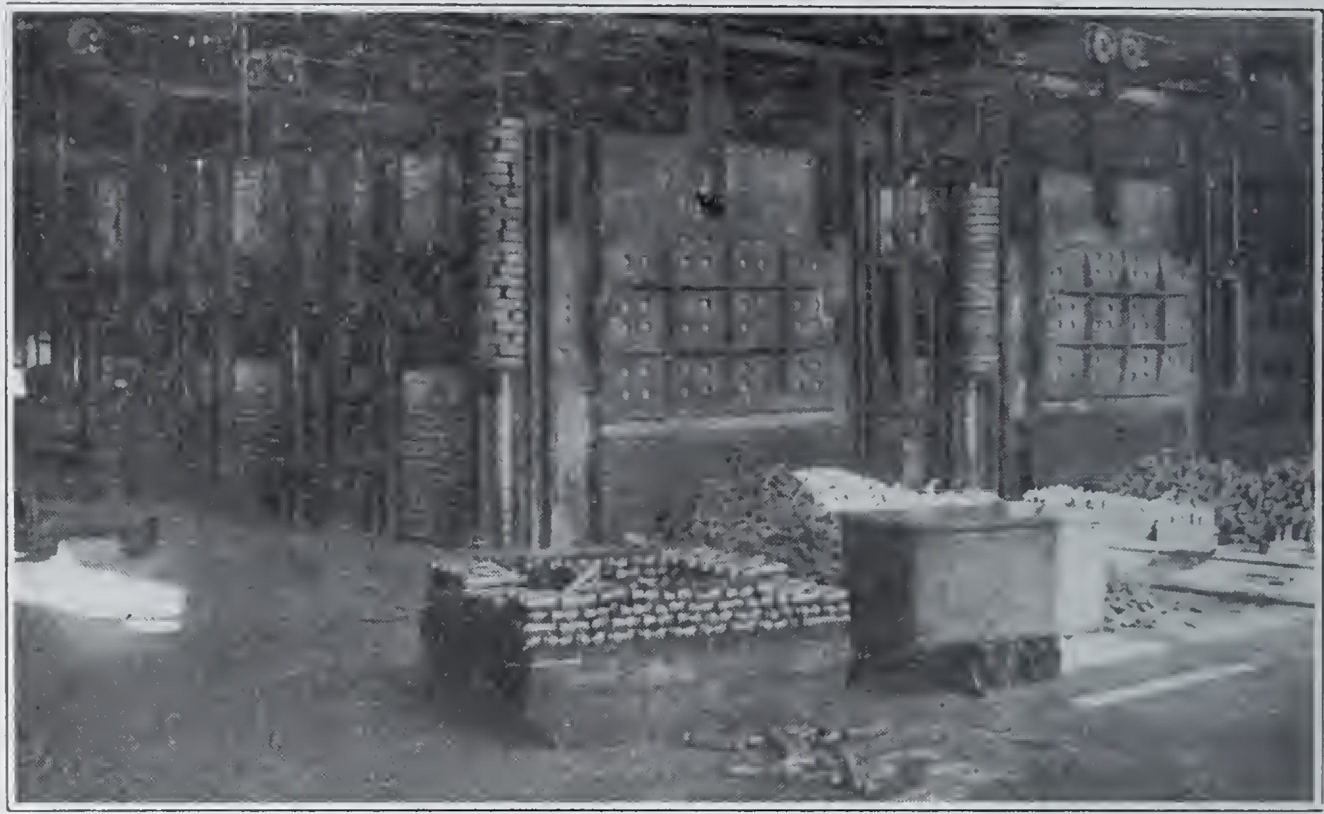

Fig. 10. Surface Combustion Annealing Furnace of Car-Bottom Type for 40,000-Pound Charges of Rifle Parts. Closed Annealing Boxes Were Dispensed with. Coke-Oven Gas Used as Fuel.

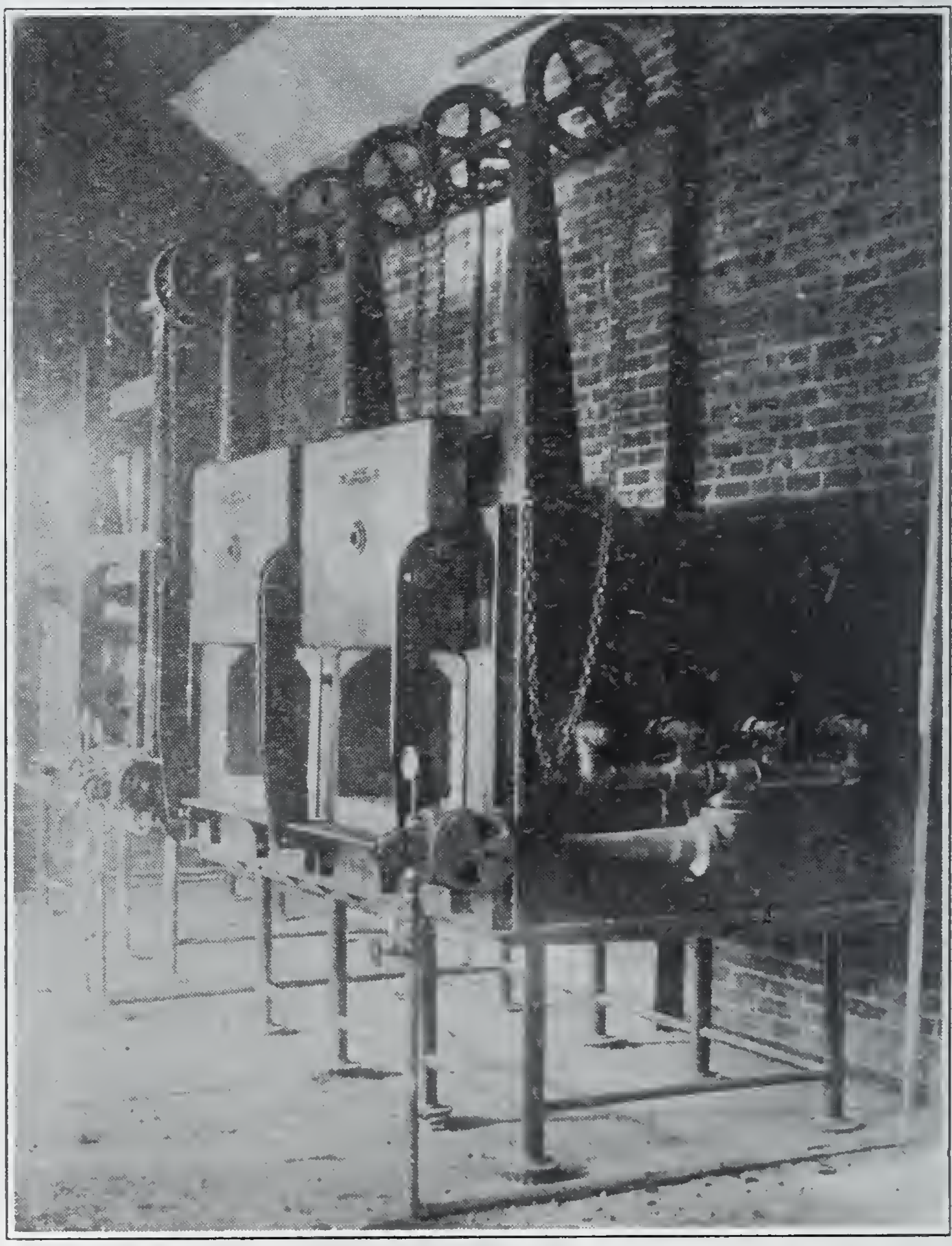

Fig. 11. Surface Combustion Carbonizing Furnace. Coal Superseded by City Gas. Output Quadrupled.

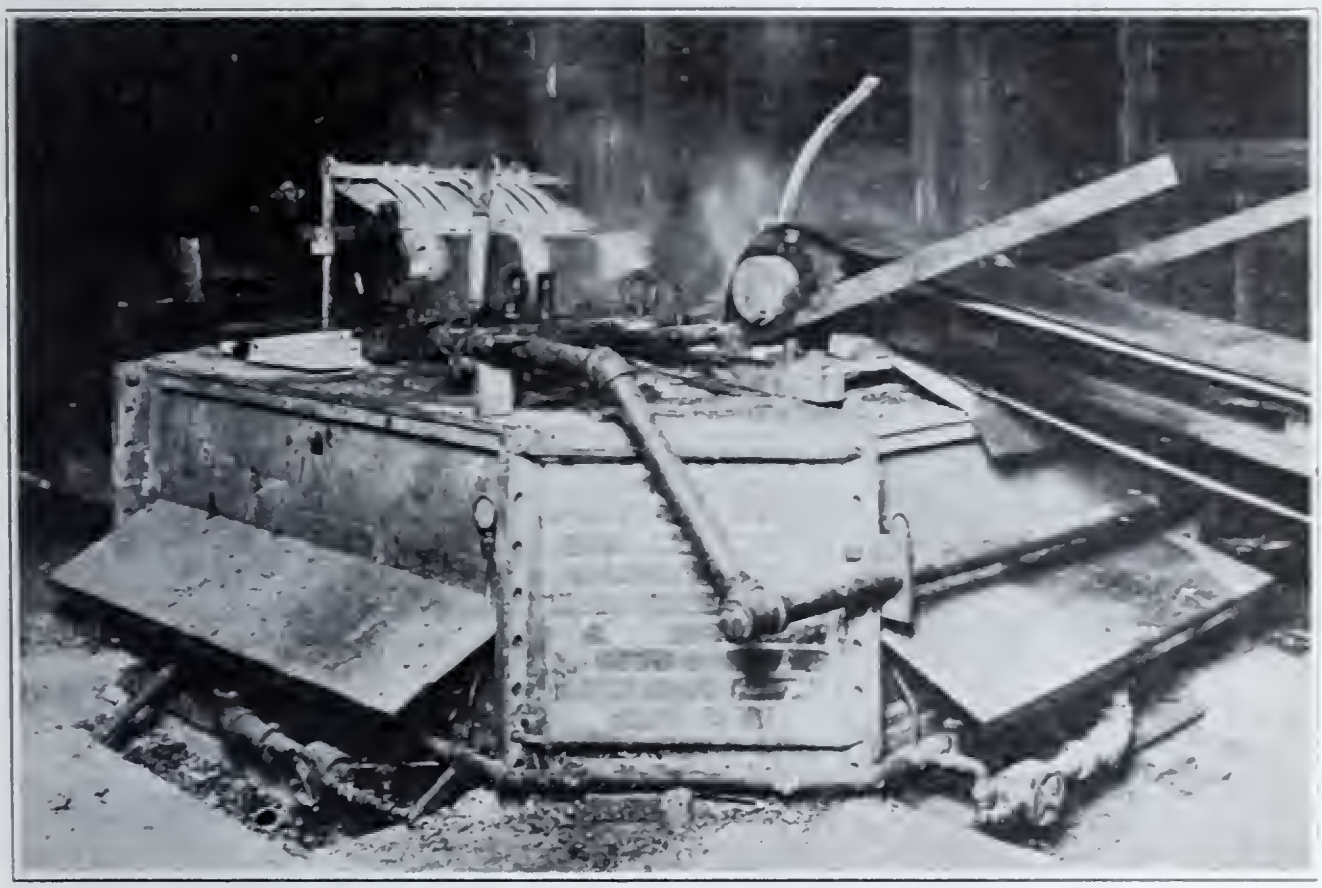

Fig. 12. Surface Combustion Continuous Sheet Galvanizing Kettle. Coke Superseded by City Gas.

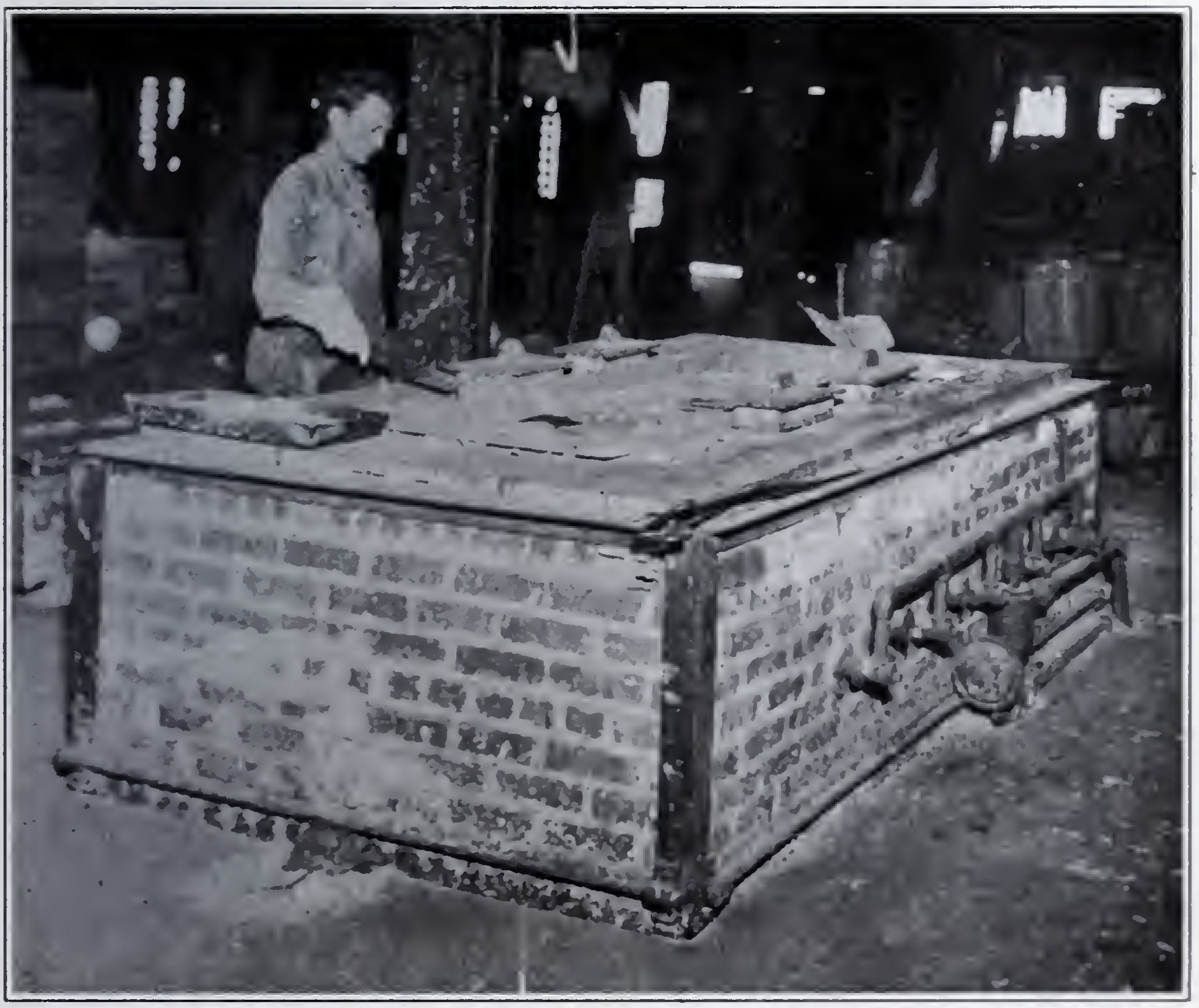

Fig. 13. Surface Combustion Galvanizing Kettle. Coke-Oven Gas Fuel.

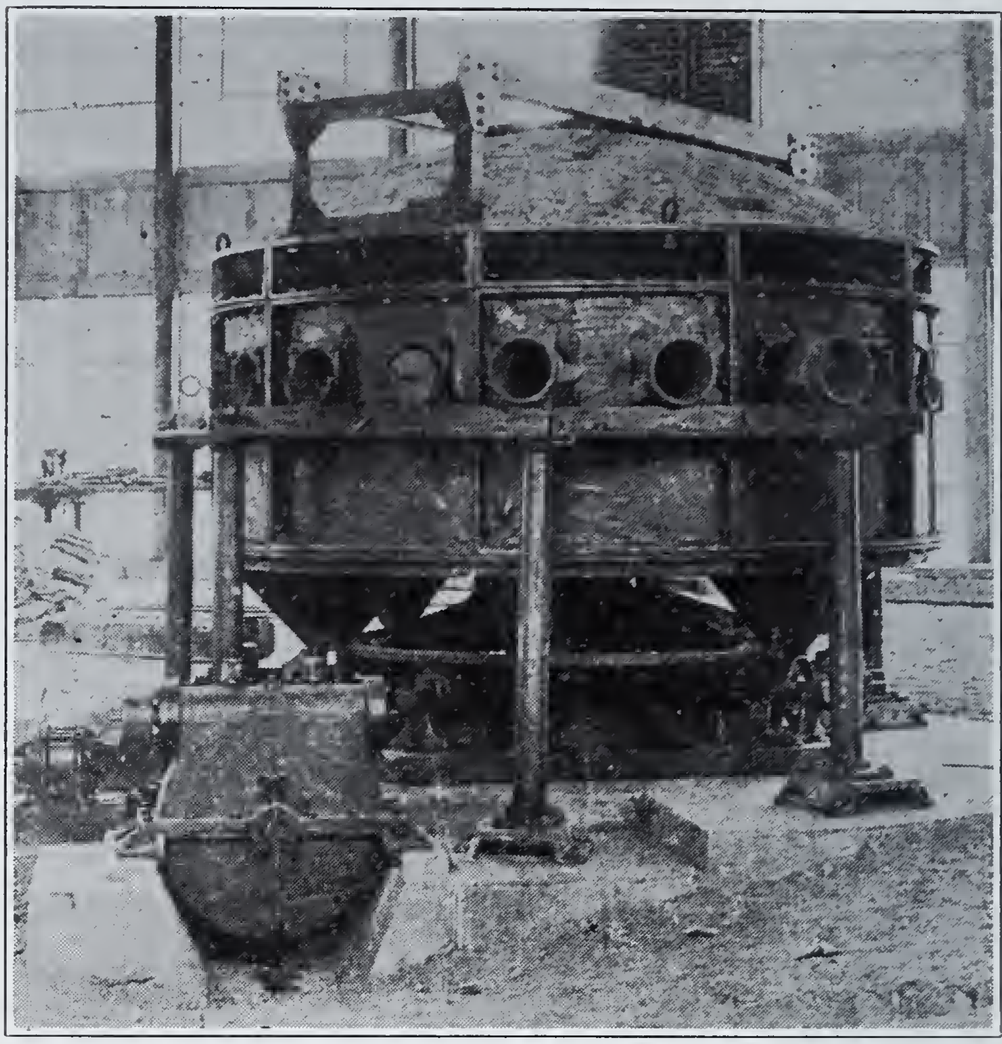

Fig. 14. Surface Combustion Swaging or Nosing Furnace for Six-Inch Shell. Frankford Arsenal. City Gas Fuel. Shells Rotate in Place and Entire Furnace Revolves. Output 120 Shell per Hour.

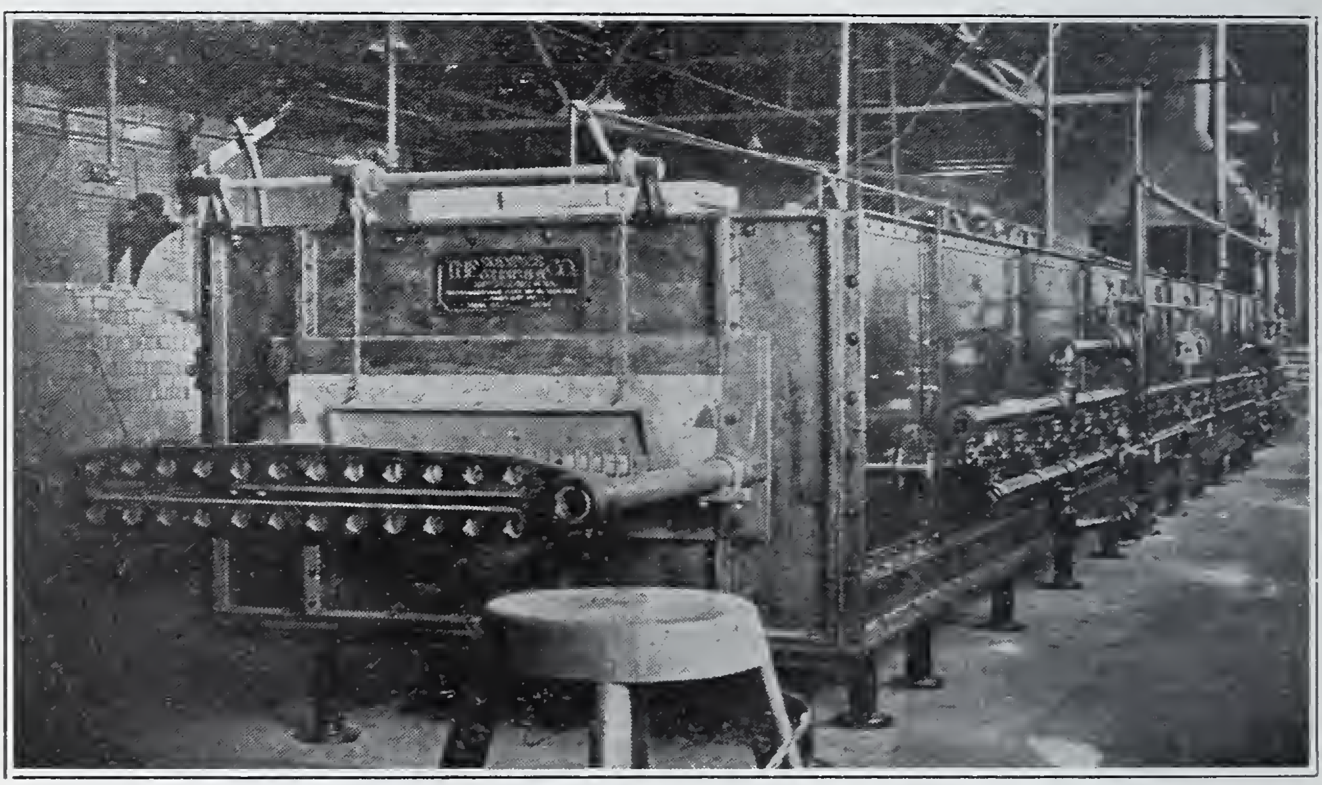

Fig. 15. Surface Combustion Wire Patenting Furnace—Intake End.

Fig. 16. Surface Combustion Wire Patenting Furnace—Delivery End.

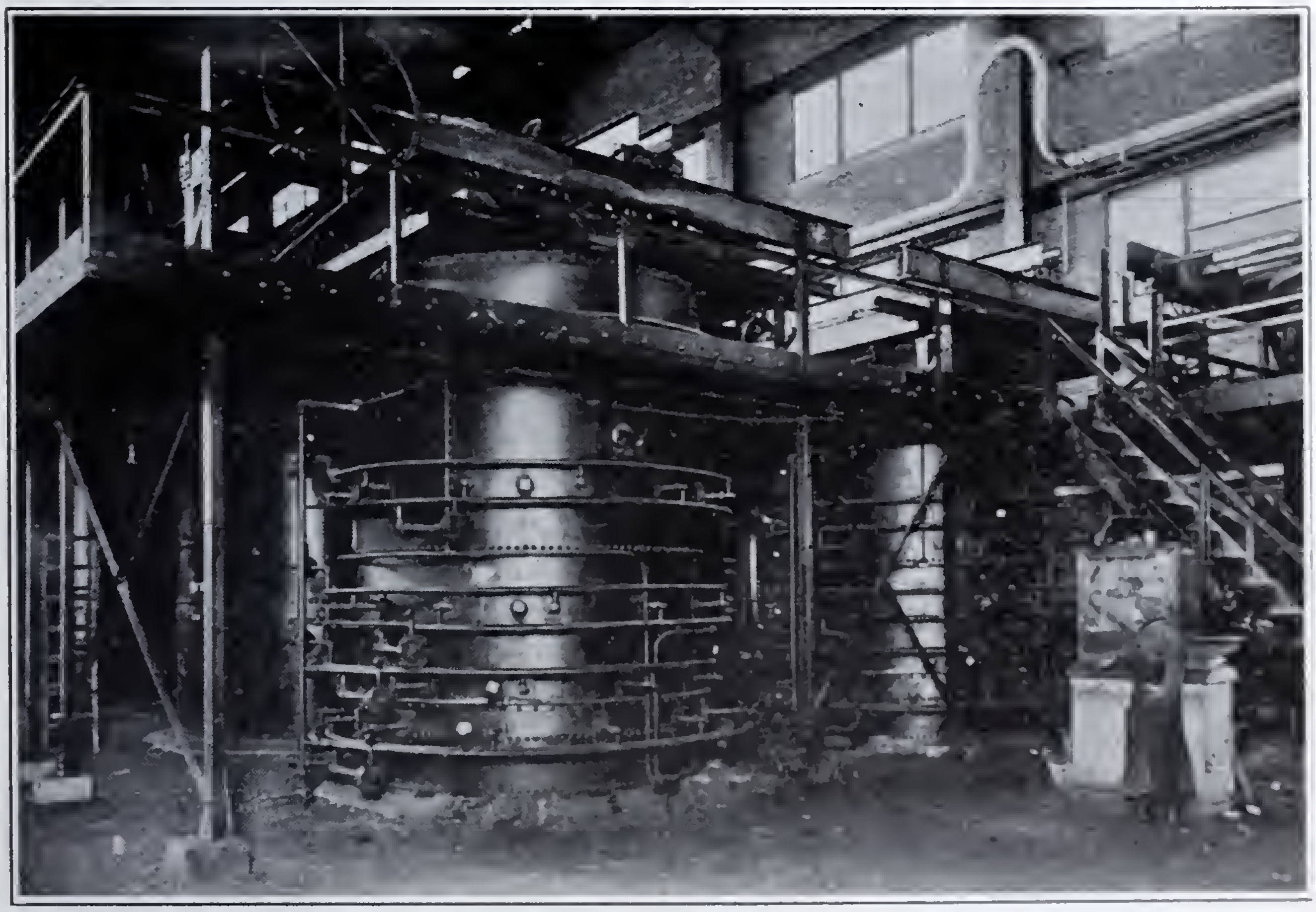

Fig. 17. Battery of Surface Combustion Heat Treating Furnaces for Quenching and Drawing Cannon Tubes. Watertown Arsenal. Boston City Gas Used as Fuel.

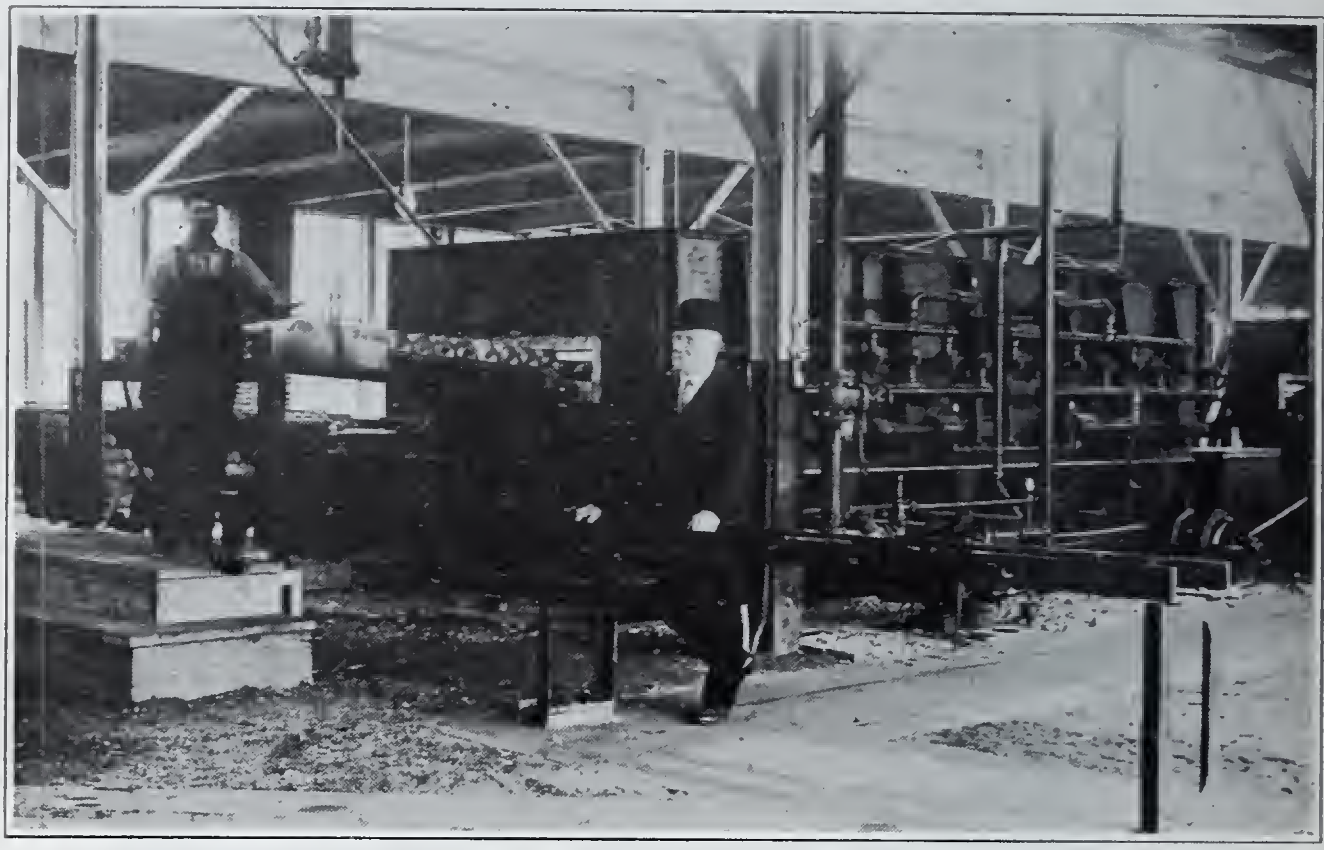

Fig. 18. Automatic Surface Combustion Shell-Quenching Furnace. Pawtucket, R. I. City Gas Used as Fuel.

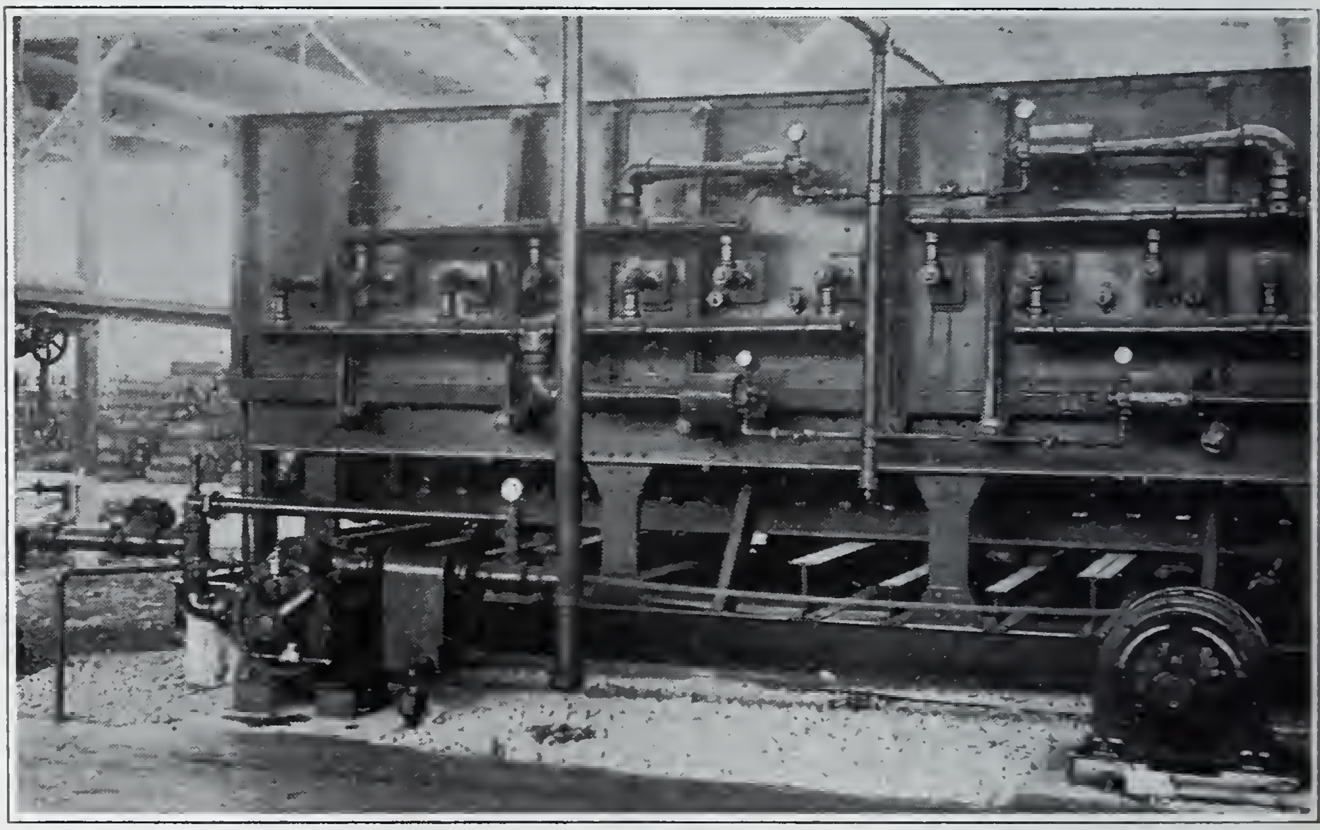

Fig. 19. Automatic Surface Combustion Shell-Drawing Furnace. Pawtucket, R. I. City Gas Used as Fuel.

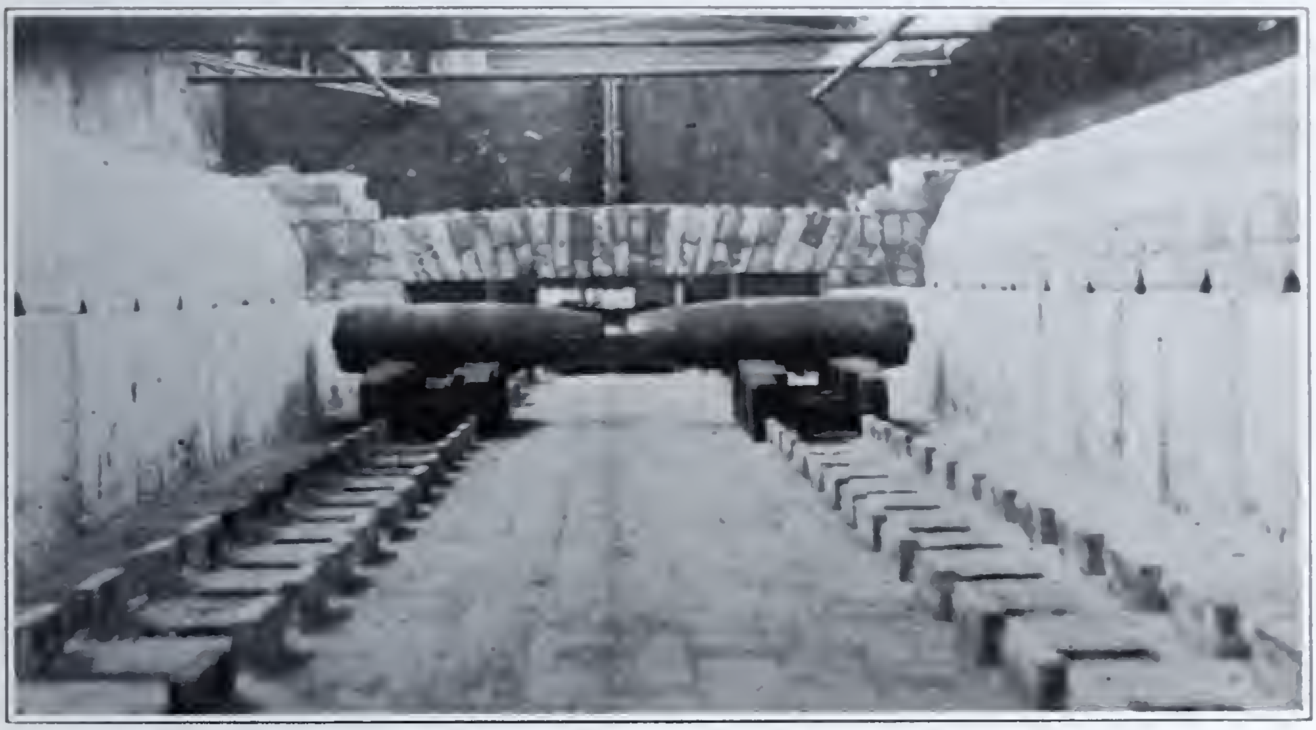

Fig. 20. Incomplete Interior of Installation Shown in Fig. 18.

Fig. 21. Surface Combustion Tinning Pot—One of a battery of 42. Coke-Oven Gas Used as Fuel.

Fig. 22. Battery of Surface Combustion Lead-Melting Furnaces for Continuous Melting in an Electrotype Shop. City Gas Used as Fuel.

Fig. 23. Small Surface Combustion Forge.

Fig. 24. Surface Combustion Rivet Heater. Width of Opening 5.5 Inches. Output 100 Pounds per Hour.

Fig. 25. Continuous Forge Furnace. High-Pressure System, Using Producer Gas at about Eight Ounces Pressure.

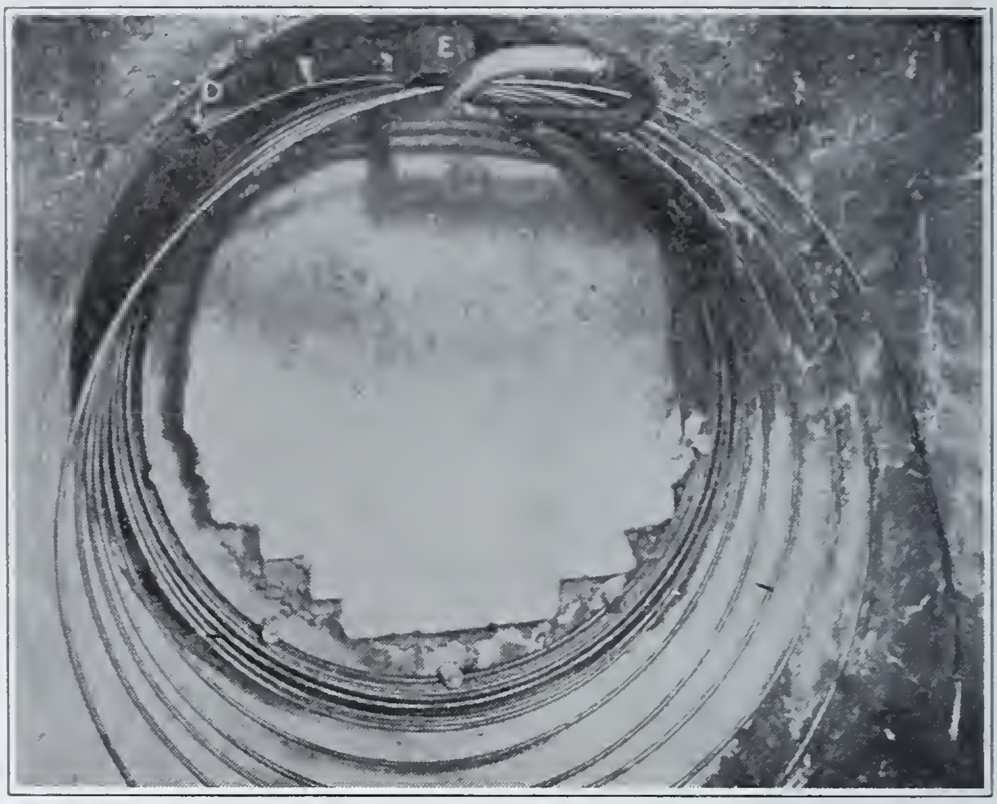

Fig. 26. Furnace Interior of Installation Shown in Fig. 25.

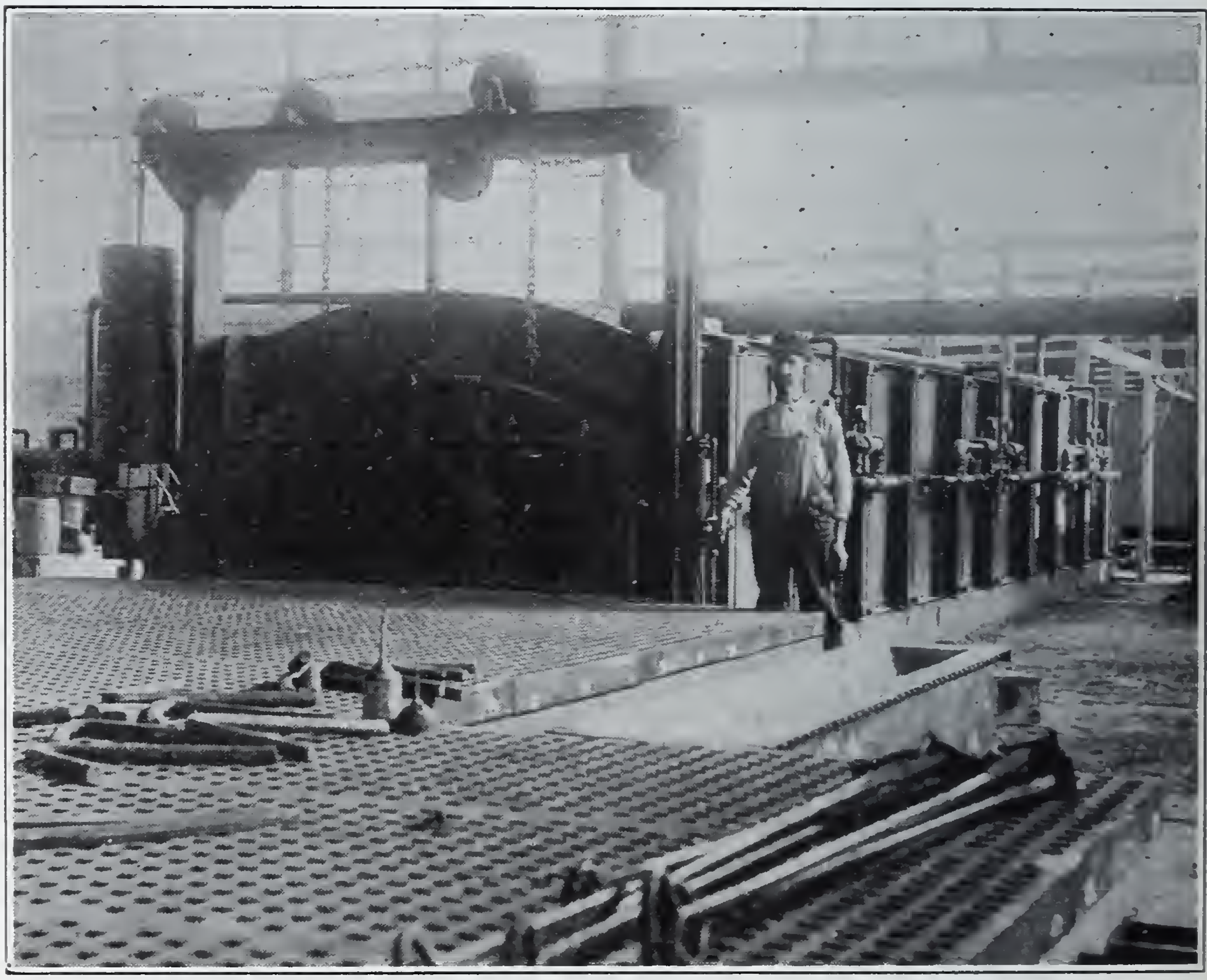

Fig. 27. High-Pressure System, Using City Gas. Hot Shaping Furnace for Heating Ship Steel.

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DISCUSSION

Mr. A. F. Mitchell:* At the present time, when fuel economies are of great importance, the question of complete combustion, so as to get the utmost efficiency out of the fuel used, is one that should be extremely interesting to many industrial concerns.

The paper that Mr. Blake has presented contains many valuable points and is worthy of serious consideration.

I believe that the proper mixture of fuel and air is of first importance, and that complete combustion should take place in a flue or chamber properly located in the furnace walls. The amount of the heating mixture used will depend upon the range of temperature desired, the size of furnace, and the size and weight of the burden.

Judging from the types of furnaces that I have seen—also those described in magazines and pamphlets—I believe that the necessity of a properly controlled mixture of fuel and air has in many instances been overlooked. The result would naturally be an excess of either fuel or air. In the former case, either the unburned hydrocarbons or hot products of combustion would be carried out the flues and wasted. In the latter case, an excess of fuel would be expended upon the excess amount of air. This could be summed up by saying that this type of furnace is both inefficient and expensive as far as fuel is concerned. Suppose we follow this a little farther; first, when combustion occurs within the furnace the burden is not heated uniformly, and, as a result, it is either overheated at certain spots or unnecessary time is wasted in adjusting the burners or soaking out to get the heated material uniform in temperature; second, when combustion takes place within the furnace close to the roof or side walls the brickwork is bound to suffer; this is especially true in the case of high-temperature furnaces. I believe that the failure of steel parts to meet the required physical tests after heat treatment is due in many cases either to overheating or to uneven

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heating at some time during the operation; and, further, that this is not so much the fault of the furnace operator as of those responsible for the type of furnace installed.

Many of the so-called necessary evils at present connected with heating furnaces could be eliminated by carefully studying out our individual heating problems and applying some of the principles suggested by Mr. Blake in his paper this evening. I feel satisfied that the time would be well spent and the results gratifying.

In connection with the Neville Island project of the United States Steel Corporation, I desire to state that the engineers in charge had fully decided—after careful consideration of at least a dozen different types—to install the surface combustion furnaces for heat treatment and heating for nosing of all high-explosive shells. This installation was to cost approximately one and one-half million dollars. At that time I was Metallurgical Engineer for the above project.

The United States Naval Ordnance plant recently installed one vertical, gun-tube, heat treating furnace equipped with mixers and burners supplied by the Surface Combustion Company. This furnace is 5.5 feet, inside diameter, by 21.5 feet deep, and does not have any interior "honey-combed" baffle wall, exit flues or stack. The tubes are heated, for either quenching or tempering, to ± 5 degrees from end to end, and are plainly visible at all times. To those familiar with vertical furnaces the value of this type will be apparent.

On the strength of the above, another larger vertical furnace, approximately 12 feet, inside diameter, by 50 feet deep, has been contracted for with the same company.

Mr. Grant D. Bradshaw:* I would like to ask if the speaker has had any experience with continuous, billet-heating furnaces. He mentioned the difference in changing from a luminous flame, extending the greater length of the furnace, to a higher temperature zone of practically flameless combustion in the front. Does that cause a decrease in the capacity of the furnace?

*President, Andrews-Bradshaw Co., Pittsburgh.

This point is brought to mind by my experience in changing a furnace of that type from producer gas to stoker firing. The effect was to increase the front temperature very materially, getting what I would consider much clearer flame conditions; in fact, the conditions which would be approximated by surface combustion, with a consequent reduction in stack temperature. The effect, however, was to reduce the capacity considerably, even though economy was very much improved. I wonder what your experience has been along those lines.

Mr. A. E. Blake: We have not applied anything to a furnace of the type you describe; but, if we were going to do it, we would not put all the burners at one end. A furnace of that type is usually much expanded at the delivery end. There is a great space provided for the existence of flame. We do not think that is necessary, when flame is to be eliminated. To heat such a furnace, we would put a few burners at the end, just as we would locate them if we were going to fire with a flame, and, along each side, tunnel arch burners would be located to produce a zone of reverberatory heating as long as the former enlargement in the roof. We would then have a clear furnace and a high-temperature zone long enough to insure that the billets would be heated rapidly and soaked well enough to be ready for the mill at normal or increased rate. I would be perfectly willing to guarantee that. I know of some engineers who tried surface combustion without any burners along the sides, and got the identical results you mention. The slabs were 8 by 22 inches. The first slab was very well heated. The next one was only about half heated. I am sure that if a number of burners were placed along the side, plenty of radiation equal in intensity to the displaced flame would be produced and uniform heating and soaking would result.

Mr. Grant D. Bradshaw: Of course, in putting coal in a furnace of that kind, side heating would be impracticable.

Mr. A. E. Blake: Absolutely so.

Mr. Grant D. Bradshaw: The heating was all right, but capacity was reduced and the billets had to go more slowly in

order to heat properly. The effect was a decided advance in efficiency, economy, and labor, but it was too slow.

MR. A. E. BLAKE: As you look into one of those furnaces from the charging end, you see great streams of soot forming on account of improper combustion. I have never yet looked in one without this, and that is, of course, a direct waste of fuel. It occurs whether the fuel be natural gas or coke-oven gas. Flame is often drawn into the flue holes, and sometimes when the mixture is very poor, with an insufficient air supply, the stack will exert enough draft to pull air through the charging end and renewed combustion takes place in the flue. I know of one place where more combustion took place in the flue than half way up the furnace.

MR. LAUSON STONE:* You are undoubtedly familiar with the recent articles by Prof. W. Trinks in *The Blast Furnace and Steel Plant*† in which he points out that the capacity of a continuous heating furnace is a function of the combustion space. Have you any figures to indicate relative capacities of a furnace using surface combustion and the same furnace using the ordinary methods?

MR. A. E. BLAKE: We have a lot of figures on that. When we figure an ordinary, direct-fired furnace, we usually calculate the amount of gas to accomplish the work, to be about four times the amount it would take to maintain the furnace at the operating temperature without working. That is only a general rule, and it does not always hold. In the case of continuous furnaces, however, in which there is ample opportunity to preheat, the ratio of holding consumption to working consumption will be very different. The fuel to be used, the class of work, and other varibles can exert so much influence that it is hard to conceive of any guide in the matter, reliable enough to be classed as a law. The proof of such a law would attract wide attention.

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†Heating furnaces and annealing furnaces. (Serial, beginning Ja 1919.)

Mr. Lauson Stone: You do not know what effect the use of surface combustion would have on Professor Trinks's law of capacity?

Mr. A. E. Blake: I have not studied that law, though I have promised myself that I would read all his articles as soon as all are published. We do not make use of any such law ourselves.

Mr. Lauson Stone: It would be, I think, of considerable interest, if you could take a furnace that has been rated at a given capacity and by installing surface combustion in exactly the same furnace you could increase the capacity.

Mr. A. E. Blake: I have seen a number of furnaces such as we are discussing and have guaranteed to increase their output by as much as 50 per cent. Increases of 100 per cent. have been common in the case of other types of furnaces. It was 400 per cent. in the case of carbonizing to which reference has been made. That does not depend on any particular law. Sometimes the difficulty seems to be that they do not know how to make burners that will pass enough gas to do the work. I have in mind a billet heater that only needed to burn more gas to have more output and at higher efficiency. That particular type of furnace *ought* to have a larger ratio than the one I have mentioned because it is the preheat type. Your efficiency, of course, is largely dependent upon the amount of heat you can abstract from the flue-gas before it leaves the furnace.

Mr. Wilbert J. Huff:* As I understand that this paper will be published, I believe that the author will not object to a criticism upon one of the minor statements. Free carbon in a luminous flame is not produced by the preferential combustion of the hydrogen in the hydrocarbons. In a series of papers on the oxidation of methane, ethane, ethylene, and acetylene, published in the *Journal of the Chemical Society* from 1902 to 1906, Dr. W. A. Bone and his collaborators have shown that there is no preferential combustion of either carbon or hydrogen, but that both elements are attacked simultaneously. The free carbon

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is produced by thermal dissociation, which at the same time produces free hydrogen. I believe that this work by Dr. Bone preceded his study of surface combustion, and, if so, it may have directed his attention to the researches which led to the development of this process.

Mr. A. E. Blake: I thank you very much for mentioning that. You will note that the paper contrasts flame firing with flameless firing and, in the case of flame heating, emphasizes the necessary delay in combustion due to the time requirements for interdiffusion of air and gas to produce mixtures which can burn. Suppose methane enters a hot enclosure from an orifice and streams along parallel for a time with streams of air which will ultimately consume it. I will grant that the gas can dissociate and that it probably breaks first into CH_2 and H_2. This would afford opportunity for some preferential combustion, since the hydrogen would diffuse the more rapidly.

Admitting that the dissociation goes to the point at which carbon atoms are liberated, these would for the time being be enveloped in hydrogen gas having well-known and preferential affinity for oxygen. I do not recall the temperature at which hydrogen reduces carbon dioxid but do not believe it is high. The atomic carbon would find itself suspended in the gaseous state, to all intents and purposes, save one, namely, that the carbon atom probably requires more energy than any other to enable it to remain in the gaseous state, and it is utterly impossible for that much energy to be available under the conditions. As a result, carbon assumes the solid state, with the formation of colloidal or subcolloidal particles. These, in turn, are oxidized when hydrogen is out of the way, the first product being carbon monoxid and the second carbon dioxid, provided sufficient oxygen is available. This may all take place in the furnace, or much of it may take place in the flues or on the outside. The latter condition is, of course, to be avoided. The energy generated in the neighborhood of the carbon particles by combustion in the various stages is transmitted to the carbon by impingement and the result is the familiar sea of incandescence so relied upon as a source of radiant energy.

The early work of Bone had to do with such mixtures as electrolytic gas, and then with the various hydrocarbons and oxygen, or air. The word *mixture* should be emphasized. *Solution of gases* expresses it better, because homogeneity is implied. When such a mixture was heated to the point of dissociation of one of the constituents, or nearly to that point, if the ignition temperature was somewhat lower, it was found that combustion was complete in time intervals of molecular dimension. The energy already possessed by the gas molecules of the mixture requires little addition to produce reaction throughout, and that generated at the point where ignition begins supplies the remainder necessary to detonate the mixture and cause reaction. It seems hardly necessary to insist that the rate of combustion in this instance is chiefly due to the thoroughness of the mixture. Further, when determining the rate of combustion of perfect mixtures at ordinary temperatures and in very long, small-bore, glass tubes, no white flame was ever mentioned, but rather a thin, blue zone, so long as it traveled slowly enough to be seen. This undoubtedly led Bone and his associates to conclude that combustion is not preferential. For *intimate mixtures* they surely were justified in their conclusions.

Mr. W. J. Merten:* Mr. Blake, in his theoretical discussion of surface combustion, regards the molecular resistance of the inert gases of improper mixtures as one of the factors of improper heating. It is probably the cooling effect of the excess gases rather than the molecular resistance of the inert gases; for you have those inert gases present in large quantities at all times, whatever your mixtures may be.

Mr. A. E. Blake: I regard the cooling effect of excess air to be a very great detriment to efficiency in heating, and for that reason have illustrated that effect, to all intents and purposes, in Fig. 1. In Fig. 2, I showed the combined effect of heating up excess air at the expense of the work to be heated, and of molecular interference of excess air with combustion. It is certainly

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true that there is always the inert nitrogen of the air to reckon with, even when using a perfect mixture. This is beyond our control, but removal of excess air is not.

Mr. E. E. Ross:* Is there any advantage in using one sort of refractory material rather than another, especially at low temperatures? I should imagine that some materials would show better catalytic action than others.

Mr. A. E. Blake: I have not paid very much attention to that because it is an unimportant feature; but I believe Bone, in some of his work, has remarked that certain grades of refractory material—of different porosity, etc.—have a marked difference. But when we go out for a refractory for this kind of work we choose something that has the highest possible fusion point consistent with the price of it, and there happen to be two very good materials at a fairly reasonable price—alumina and carborundum, and we stick to them pretty closely.

Mr. E. E. Ross: In the comparatively recent experiments of J. J. Thomson on electrical conductivity of gases, it has been found that many solid materials, when incandescent, give off electrons; the amount of such emanation, however, varies greatly with the kind of material and temperature. Is there any noticeable advantage in the action of the furnaces when different refractory materials are used, especially in furnaces for low-temperature work? Apparently your work is chiefly concerned with high temperatures.

Mr. A. E. Blake: Dr. Bone's writings contain slight references to the influence of ultra-violet light. I do not recall that he mentions the possibility of ionization, production of electrons, or of gamma rays. The work of J. J. Thomson does not appear to have been sufficiently advanced at the time Bone was looking for explanation of the phenomena he had discovered.

You should not suppose that surface combustion can be applied to high-temperature work only. It is used in baking bread,

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making varnish, melting lead, distilling petroleum, galvanizing, tinning, and annealing.

Mr. Edward Rahm, Jr.:* As I understand your explanation of a perfect mixture you refer to the proportion of gas and air, rather than to the thoroughness or intimacy of the mixture.

Mr. A. E. Blake: Not a perfect proportion, exactly. By a perfect mixture we mean a quantitative, homogeneous mixture. But we do not need to have a perfect mixture in order to have surface combustion. All that is needed is a homogeneous mixture of such proportions as to support combustion. If you have a mixture in which air and gas are present in proportions that will support combustion you can have surface combustion just the same.

Mr. Edward Rahm, Jr.: I see what you mean. According to my first idea your flame could be neither reducing nor oxidizing and your apparatus would, therefore, be ruled out for such classes of furnace application.

Mr. A. E. Blake: No. There would be surface combustion just the same. It was hard to get perfect combustion when they first started out, because they had a two-valve control, and there was nothing automatic about it. That is the common complaint with the ordinary burners made at present. A good many of them are capable of giving you a good homogeneous mixture but it does not come anywhere near remaining perfect. You have to depend on the ordinary operator to keep it in proper adjustment and he may not be interested in perfect combustion, but rather in the sound of the whistle telling when to quit work.

Mr. Wilbert J. Huff: Mixtures of gas and air in the proportions required to produce complete combustion without excess, or mixtures which closely approximate these, are very explosive. What precautions, if any, are taken against this hazard?

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Mr. A. E. Blake: You or I could go into a factory and explode every ordinary furnace in it without half trying. No insurance company has ever called our attention to the fire hazard of using surface combustion. Occasional back-firing through the manifold is never hurtful to the apparatus. It was designed with this in mind. The orifices of the burners are constricted to a point, to make them fool-proof, so as to give continuous operation and prevent back-firing unless the mixture is passing at a pressure less than 0.2 inch water-gage, except in the case of water-gas which requires a little higher pressure. When it does backfire you know that something has happened, but nothing occurs except a sharp noise.

Mr. F. F. Espenchied:* While this paper is of considerable interest, showing a great number of applications of successful gas-heating appliances, the title of the paper is somewhat confusing. Surface combustion as originally defined, is the combustion of gas in the presence of porous, granular refractories. The author began his illustrations with a picture showing a furnace of this kind, and intimated that the extremely high temperatures attained were difficult to control.

It seems to work out, however, judging from the author's description and pictures, that this so-called surface combustion scheme is nothing more nor less than a method of mixing gas and air to secure perfect combustion, evidently in most cases without any porous refractories. There are numerous methods of securing so-called perfect gas and air mixtures and I believe that no engineer will attempt to deny the desirability of properly controlled mixtures. The term, surface combustion, as applied to the equipment described is, to me, confusing, in that it appears to be nothing but one of several possible methods of securing and controlling the proper mixing of air and gas. In other words, it would appear to be a paper describing successful gas burners and gas mixers.

Mr. A. E. Blake: It is to be regretted that the term surface combustion is confusing. As explained in the beginning, it

*Steam Plant Engineer, W. E. Moore & Co., Pittsburgh.

is the outgrowth of work in metallic catalysis of gas reactions and now, to some extent, may be a misnomer. The investigators did not seem to realize, at first at least, that they made a distinct departure from their original line of work when they abandoned metals. The facts are, however, that the grounds for retaining the name were good; that those who developed the process deserve credit for the accomplishment of results which will continue to benefit mankind so long as gas is used as fuel; that they are entitled to much consideration in their preference for a name; and finally, when they had commercialized the process, as was their duty, it would be too much to expect them to forego the "good will" which had been built up under the name and through their efforts.

I am sorry, but I cannot agree to your definition of surface combustion. You overlook the very essential requirement that gas be homogeneously mixed with air before the two arrive at the theater of operations; also, that the proportion of air to gas must be such that they will ignite and support combustion. I have found it so difficult to write a brief definition of surface combustion which I could feel sure would meet with general approval of those familiar with it, that I have preferred rather to let it take the form of the paper I have presented.

I have no recollection of having remarked that high temperatures are difficult to control. It is not in the paper which I have read. On the contrary, the small furnace first shown, and described as useful in fusion testing, can be easily manipulated to follow any prescribed time-temperature heating curve within very wide limits: Cone 36 has been fused in 25 minutes, but the fusion can be extended over a period of hours, if desired.

Mr. Espenschied's next remarks show that he has what may be termed a good practical grasp of the process. I have only troubled to show you two or three ways to prepare and use a desired mixture of air and gas. Those in control of the basic patents for the process are not especially concerned as to the means employed so long as each case is handled to the best possible advantage.

I am sorry if this gentleman's confusion arises from difficulty

in differentiating between the process and the apparatus which is used in accomplishing it.

Mr. F. F. Espenschied: Is it not true that the original furnace was made to pass gas mixture through the incandescent bed of porous, granular refractories? To most engineers not specializing on this work, my impression is that this scheme represents the only true surface combustion, but perhaps I am in error in this instance.

Mr. A. E. Blake: Yes, the gas mixed with air, as previously stated. If it pleases anyone to take the view you express, I am satisfied; but those in charge of commercial application might be pardoned, I think, if they do not care to be so limited.

Mr. F. F. Espenschied: From your description and pictures it seems to me that you have gone far afield from so-called surface combustion when you are firing a gas mixture without any porous granular refractories at all, relying entirely on the refractory material in roofs and walls. There seems to be nothing original in this, whatever.

Mr. A. E. Blake: I should say that about half the furnaces described have the impact type of burner with the refractory bed. The rest of them have the tunnel type of burner. In our opinion it makes no difference, because we do not believe actual mechanical contact between the gases to be burned, and the solid which is to exert its influence, is at all necessary. It is the influence of the ultra-violet light that counts, and that might operate at a distance of one or two inches, or, in the case of the earth receiving energy from the sun, over some 93,000,000 miles—actually performing work; so surface combustion, instead of being due to catalysis of a solid is due to catalysis of light. Even though you shoot a stream of perfect mixture into a pocketed bed, it is very doubtful indeed if five per cent. of the molecules in that mixture actually impinge upon any of the solid, on account of the space arrangement of the gaseous molecules—yet we have surface or flameless combustion just the same.

They used to suppose that the surfaces did have influence and I still think that in catalysis action below the ignition temperature when platinum, or other metals of that family—gold, silver, copper, nickel, iron, etc.—are used, the solid actually does have a great influence. Occlusion of gases may occur, especially of hydrogen. That occlusion generates heat, preheats the mixture, and gives ground for belief that it promotes the reaction. Spongy platinum could not be used, due to the high rate of occlusion and speed of heat production.

I have often wished to have the refractory bed overlooked because disappointment is often caused by its omission in furnace design. On the other hand, many cannot see how we would place such a bed in their furnaces, and are finally glad to know that it can be dispensed with in their particular cases. This only serves to emphasize the importance of automatic proportioning and the one-valve control system, since, as you say, there is nothing new in projecting air and gas into a furnace chamber.

Mr. F. F. Espenschied: You might give us some idea as to refractories. Being formerly connected with a stoker concern where we had considerable trouble with roofs and arches, it would be interesting to know what you can successfully use for temperatures up to about 3700 degrees F. which it appears you can obtain with your burners. We were not successful in finding a practical material for these extreme temperatures, particularly when washed by gases at fair velocities.

Mr. A. E. Blake: Much of your trouble was probably due to slagging caused by coal ash. Millions of dollars are spent in repairs by those who fail to take such costs into account when comparing the cost of raw coal firing to the cost of heating with gas.

For the special small furnace, if temperatures above 3700 degrees F. are to be resisted, the substance that would be most likely to withstand anything you could bring against it, would be pure zirconia. It is available in fairly large quantities now.

Mr. F. F. Espenschied: Yes, there are some makers of so-called rare-earth bricks who offer them for severe service, but

at a price of from $1.10 to $1.35 apiece f.o.b. factory. The use of such material would be very limited.

Apparently, the author's process is more applicable to low-temperature gas heating than it is to high-temperature melting, and I am sorry that we have not learned more about refractories and their life. I was interested in seeing illustrations of the many successful gas-heating furnaces installed by the company Mr. Blake represents.

Mr. A. E. Blake: Your problem is to get the zirconia properly bonded. It will resist temperatures in the neighborhood of 6200 degrees F. This does not refer to the natural material as received from Brazil, but to the chemically pure article. The matter of attaining these extreme temperatures is of academic interest only, except in very few instances. For continuous, high-temperature work in the steel and glass industries, silica will do very well, but for ordinary work, clay brick serves the purpose as well as any. When expensive slag-resisting brick is called for in ordinary gas-fired furnaces, it is generally necessary to use it in a surface combustion furnace.

It should be borne in mind that while this process enables the attainment of unusually high efficiency in direct-fired furnace work, the higher the temperature called for, the less it is able to compete with regenerative firing. That is why surface combustion has not been applied to the open-hearth process and to most kinds of glass melting. The difference between discharging flue-gas at, say, 2900 degrees F. and at 1000 degrees F. is too great for you to hope to overcome it by the use of perfect combustion. The only way to secure equal overall efficiencies in such a case would be in the use of a waste-heat boiler, in the case of melting steel, and in lehr heating, mold heating and steam raising in glass factories. In a few instances, regenerative furnaces are at a disadvantage on account of excessive dust, from glass batches, coal ash, or what not, causing rapid glazing of checker surfaces and lowering the rates of heat transfer.

For moderate temperature work, regeneration is usually out of the question, due to the space requirements, portability, closeness of temperature regulation, or of furnace atmosphere control.

Mr. F. M. Van Deventer:* In order to have surface combustion in the tunnel type of burner you presuppose a perfect mixture, do you not?

Mr. A. E. Blake: Yes.

Mr. F. M. Van Deventer: You have defined a perfect mixture as being a mechanical mixture of the molecules of the gas to be burned, with the molecules of the supporter of combustion. Another way of expressing this condition is to consider the gases "diffused." Now, the diffusion of two gases is a physical phenomenon and takes place at a definite rate which may be expressed in inches per second, the value depending upon the identity of the gases. This rate is surprisingly low; for example, about 0.056 inches per second for CO_2 and air, which means that in order to obtain diffusion (perfect mixture) in a gas burner, there must be such a relation between, (1) the distance or time of passage between the point of "admixture" of gas and air and the point at which combustion takes place, (2) the velocity of this air and gas "mixture," and (3) the distance which the gases must diffuse laterally to the direction of flow, that the gas and air may have sufficient time to diffuse according to the characteristic rate of diffusion.

Examples of the effect of these conditions upon the design or operation of furnaces or burners are noticeable in the following:

1. The high boiler furnace in which a great distance of travel (and consequently considerable, time) is allowed, in order that the air and the gases distilled from the coal bed may be diffused, and burn before reaching the chilled boiler tubes.

2. The fact that, when a furnace is forced, a point is usually reached beyond which combustion becomes increasingly incomplete, due largely to the fact that the velocity of passage of the gases through the furnace is so high that diffusion cannot be completed in the time of passage.

*Engineer, National Tube Co., Pittsburgh.

3. In many gas burners; instead of forcing a single jet of gas into the supporting air, a nest of small jets is used, thus decreasing the average initial distance between molecules of the two substances to be mixed.

I would understand that in the tunnel type of burner the gas enters the aspirating tube in a single jet; the velocity of the gas and air must be higher than the velocity of flame propagation (relatively high) up to the "surface" of combustion; the distance traveled in the direction of flow is very short, and thus the time is short. These factors are opposed to the conditions for a perfect mixture as explained by the phenomenon of diffusion.

While this contribution to the discussion is entirely theoretical and probably of little practical merit, I believe it would be enlightening, and not beyond the theoretical aspect of the paper, if you will explain how a perfect mixture obtains from the tunnel type of burner.

Mr. A. E. Blake: While I regret that the gentleman has missed the point that the burners and inspirators which have been described are entirely separate and distinct pieces of apparatus, I am glad the opportunity has been afforded of placing emphasis upon so important a feature. The air and gas are accurately proportioned in the inspirating device and the rate of formation of mixture is governed by a single valve. Due to the design of the entraining tube, a certain amount of desired friction is set up and is utilized in the formation of eddies in one of the fluids, at least. These eddies continually seize upon the other fluid and promote mixing. In fact, it has been pretty thoroughly demonstrated that mixing is practically complete at the end of the entraining tube. From here on, however, the gases pass through various ells, long nipples, tees, etc., to the various burners in the battery which the inspirator serves. There may be from one to a dozen burners in such a battery.

As regards perfect mixing, and its effect upon removing the condition where CO and O_2 are found in the flue-gases, I might say that several rubber companies use surface combustion equipment to produce neutral flue-gas, for use as a cheap inert gas in

the recovery of rubber solvents. One concern also recovers the heat produced by means of a steam-boiler. The gas must be free from O_2 and CO down to about ± 0.2 per cent. Another concern has used the apparatus as a means of securing a constant supply of atmospheric nitrogen, CO_2 and water vapor being easy to remove. I will include here a couple of analyses taken from the first pass of a Babcock & Wilcox boiler to which surface combustion apparatus was applied. Dirty blast-furnace gas was the fuel.

CO_2	O_2	CO	N_2 (difference)
25.0	0	0	75.0
24.2	0	0	75.8

On another occasion, two tests of flue-gas from the first pass of the same boiler showed the following results:

Date	Time	CO_2	O_2	CO
June 2, 1919	10 a. m.	25 per cent.	0.3	0
June 2, 1919	11 a. m.	24.4 per cent.	0.6	0

Similar results were obtained with smaller equipment.

The following abstracts from a letter reporting results in steam raising with 100 B.t.u. producer gas in France may be of interest, because they show that forcing is not only possible, but that the only limiting factor encountered is the supply of feed-water:

"We just put an oily rag in front of the bürner, with the boiler cold and thirty-five minutes later she was blowing at the safety valve at 8 kg. pressure. . . . For a while we were rolling along at close to 30 kg. per square meter, but there was not enough water in the neighborhood, in spite of two feed lines which we ran to keep up this gait. . . . As a conclusion it seems safe to consider that even with a dirty boiler and a dilapidated brick setting, we can double the existing rate of evaporation, cut a boiler in on a line from cold on 30 to 45 minutes notice, and produce (at 6 kg.) an average of 1900 kg. steam per 1950 cubic meters of gas, or about 1 kg. steam to 1 cubic meter of gas. (Gas between 800–900 cal. per M^3, average 850, or less than 100 B.t.u.) . . . The overall boiler efficiency is between 73 and 75 per cent., and I feel sure this could be further increased with a proper setting."

Diffusion of gases is exceedingly slow and it is difficult to get people to realize this fact. One can expect little from any burner in which the air and gas meet for the first time, yet some of them arrange for a chance meeting, so to speak, only at the tip. The length of the flame produced by these self contained burners can be used in judging to what degree diffusion has occured. If combustion can be completed before any unburned fuel can come in contact with a cold body, no soot formation and no CO loss will occur, because no combustible material will get chilled to a temperature below the ignition point.

MR. H. P. SMITH:* It has been thought that the venturi tube might be dispensed with in order to secure more space and thereby give the gas a longer time to mix. I wish to call your attention to the function of the tube which is to inspirate the air in case of the high-pressure system and the gas in the low-pressure system. For that reason the tube cannot be eliminated.

MR. A. E. BLAKE: The expanded section is used after the desired mixing energy has been imparted and you then want as little obstruction as possible, to do away with all possible back pressure.

MR. S. G. BRIGEL:† After having secured a properly proportioned mixture of natural gas and air for combustion purposes you are sending it through pipes to your burners, as I understand it. For how long will this volume remain in a perfectly mixed state?

Suppose you were to send it a distance of 50 or 100 feet, would not the difference in specific gravity of the two substances have a tendency to separate them again and let the air settle in the bottom of the pipe and force the gas to the top; particularly, at times when the air contains a large amount of moisture?

MR. A. E. BLAKE: I have never heard of a single instance where the gases have become "unmixed," to use a common term

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†Manager, Economy Burner and Engineering Co., Pittsburgh.

for a supposed happening which has been advanced as a theory to account for the non-performance of certain long-stemmed, small, rough-bore, cook-stove burners, and where lack of good means for control exists in attempting to mix great quantities of gases continuously. In the first case, friction probably causes the trouble; the bore should be larger. In the second case, the proportion of the two gases may vary in the extreme.

MR. H. L. ABRAMOVITZ:* Regarding the stratification of gases, I wish to say that experiments were conducted on 50 per cent. mixtures of natural gas of 0.65 specific gravity, and coal gas of 0.5; also of natural gas and hydrogen. The gases were placed in cylinders 10 feet high and 2 feet in diameter. Analyses were made at one-foot intervals vertically, and the longer the tanks stood, the more uniform was the tendency for equal distribution of the mixtures. There was no tendency towards stratification after two weeks of standing.

MR. A. E. BLAKE: The specific gravity of hydrogen is 0.0692; so in the mixture referred to, one gas was about ten times as heavy as the other.

MR. W. J. MERTEN: What are you using as refractory material for your combustion tunnel?

MR. A. E. BLAKE: I think it has a lot of alumina in it. It has the consistency of molding-sand, as used. There are several refractories that will stand the service.

DR. THOMAS TURNBULL, JR.:† What are the different pressures for different gases to obtain perfect combustion?

MR. A. E. BLAKE: It depends on the weight of the gas you throw through the nozzle. Blast-furnace gas is very heavy, so two-inch water-gage is sufficient. Producer gas does not require very much air and it is pretty heavy. You need about one pound.

*Chemist, Philadelphia Co., Pittsburgh.
†Director, Tate-Jones Co., Inc., Pittsburgh.

Natural gas has low density. In West Virginia and other places we are using it at about 40 pounds pressure right from a high-pressure line. Gas companies object to that, because they say there is no meter on the market good enough to measure the gas being consumed. I think that fallacy has been overcome because we do not run into it often now. We can use natural gas at 10 pounds pressure if it is necessary to have a compressor.

Dr. Thomas Turnbull, Jr.: How is this surface combustion modified without using refractory material and how does it differ from the Smith system used in England where they put gas under pressure, bringing it in through a venturi tube and putting it in practically as you do on the arch. They make their pressure correspond to their air and gas ratio. They put most of their gas under pressure and are using it very extensively for commercial purposes and it is practically the same as your surface combustion.

Mr. A. E. Blake: When low-pressure system patents were applied for we ran into interference in England with the Keith & Blackman apparatus, and I understand the upshot of it was that these people are free to use it in England and we are free to use it in this country. I think you might say they have surface combustion. I have never seen the apparatus going and I do not know how well it functions. I think they have a two-pipe system and use air and gas, both under pressure. The Smith apparatus which you mention would seem to be a duplication of the high-pressure system which I have described and which is patented in all details here and in England. I am sure that anyone who used it here would be vigorously sued.

Dr. Thomas Turnbull, Jr.: They put the gas under pressure and induce the air with that and they are very particular about certain angles.

Mr. A. E. Blake: The people mentioned have a small device against which the gas impinges to exert an influence upon the governor.

Dr. Thomas Turnbull, Jr.: That is an elaboration that has come in since the article I have seen.

Mr. K. Marsh:* You spoke of the better heat distribution obtained with surface combustion. Do you obtain any better heat distribution by using the surface combustion, tunnel-arch system than would be obtained with an ordinary flame, or does that apply only where the material to be heated is heated directly by direct or reflected radiation from the incandescent mass at the burners?

Mr. A. E. Blake: We can reproduce about any kind of radiation effect that you may wish to have upon a furnace hearth. It is simply a matter of selecting the proper number of burners of the right size, so that they may cause radiant areas of the right intensity, in your arch. The limitation upward will be the quality of roof material.

Mr. K. Marsh: When a furnace temperature of 1000 degrees F. is desired, and the surface combustion, tunnel-arch method is used, the actual heating of the material is done by flue-gases and not by radiation from the combustion surface, is it not? Would not the advantage be confined to the saving in space and not to better heat distribution?

Mr. A. E. Blake: No volume for flame is needed in these furnaces. This reduces the wall area, thereby cutting down fuel consumption. The automatic proportioner serves as a watch-dog in preventing inefficient combustion. It is sometimes possible to assist in low-temperature heating by producing fairly high radiation effects in a small refractory bed with a small burner and small quantities of fuel. The application to bake ovens is a case in point.

Mr. K. Marsh: In reference to the vertical furnace used for drawing and quenching guns, I would like to know if the heating of the gun is done by the heat from the flue-gases or from the heat of the flue-gases and direct or reflected radiation

*Pyrometry Engineer, Aluminum Co. of America, New Kensington, Pa.

from the incandescent mass at the burners. What was the arrangement of the burners around the furnace?

Mr. A. E. Blake: Those tunnel burners are tangent to the interior and they spread the products of combustion upon the surface of the fire-brick interior, and by having burners uniformly spaced you get radiation in all parts of the furnace from the luminous strips in front of each burner. Though there is some radiation at the drawing temperatures, it is comparatively slight.

Mr. H. P. Smith: Mr. Blake explained that the pressure required by a particular gas is due to its density. Is it not also due to the amount of air required by the gas to support combustion?

Mr. A. E. Blake: The two factors are of equal importance.

Prof. W. Trinks:* Since night school keeps me away from this meeting, I follow the suggestion of your Secretary to contribute a written discussion.

Surface combustion has been practiced by Pittsburghers so long that we cannot very well determine the origin of the practice. Long before Bone, in England; Schnabel, in Germany; or Lucke, in America, experimented with surface combustion, Pittsburghers filled their natural gas furnaces with porous stones and converted the blue flame of the gas-and-air mixture into radiant energy sent out by the stones. Of course, we did not call it surface combustion, but we practiced the process so long that any patent covering the process would be void on account of previous usage.

In the third paragraph, Mr. Blake states that "the time required for reaction is what may be termed of molecular dimensions, referring to the time intervals between collisions." In the fourth paragraph he states that "At some zone surrounding the orifice, the flow speed will equal that at which combustion is propagated." The two statements do not go together, because

*Professor of Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh.

the second one assigns to combustion a definite, measurable velocity which must be very, very much slower than it would be if the time required for reaction were of "molecular dimensions."

Mr. Blake states that "Perfect combustion is the usual aim and attainment in the process being described, and, for that reason, the above term has become synonymous with surface combustion." This statement is apt to be misleading. It implies the idea that surface combustion or the equipment of the Surface Combustion Company is necessary to produce perfect combustion. Combustion engineers know that such an interpretation would be far from true. There are many other methods, long practiced in the art, of attaining perfect combustion.

The statement that "The greatest possible difference will exist between the temperature of the products of combustion and the material which it is desired to heat, in which case the rate of heat transfer will be the greatest. By shortening the time of heating, in many classes of work, much heat is saved which would otherwise be lost through the furnace walls in an extended period of firing," must be taken with several grains of salt when it comes to heating steel. I have seldom found any difficulty in heating steel rapidly enough, but have found that much trouble arises from heating it too rapidly. In the latter case, the steel cracks by having the outer layers leave the inner ones by rapid expansion. I have also seen the outer layers of billets melt off, while the center was still quite cold. If we produce such results without surface combustion, I cannot see the wisdom of raising combustion temperatures still higher.

The statements of the next three paragraphs of the paper apply with equal truth to any equipment which provides correct premixing of air and gas. They have nothing whatever to do with surface combustion. Likewise, it should be understood that the paragraphs dealing with the harmful effects of excess air have nothing to do with surface combustion, because perfect air and gas mixtures can be obtained with many types of equipment quite different from those described by Mr. Blake.

The advance copy of Mr. Blake's paper which was delivered to me does not contain any illustrations. For that reason, I do not know exactly what his Fig. 5 looks like. However, I can

judge from the description and from the previous publications of the Surface Combustion Company that it represents combustion chambers or recesses in the side walls of the furnace, and that the combustion occurs either in the furnace or against the roof of the furnace. It takes considerable imagination to call such an arrangement surface combustion, but, if it be surface combustion, engineers have been practicing surface combustion for more than 30 years without knowing it.

The air- and gas-mixing devices described by Mr. Blake are very interesting. He dwells with considerable emphasis on the claim that the air to gas ratio remains constant, while the pressure of the entraining fluid is varied over a considerable range. Many have attempted to bring about this desirable condition, but few, if any, have solved it. I sincerely hope that the engineers of the Surface Combustion Company have solved the problem, but we have no tangible proof of their having done so. In gathering material for my series of articles on "Heating Furnaces and Annealing Furnaces" in the *Blast Furnace and Steel Plant,* I have repeatedly asked Mr. Blake to give me the data of some reliable test substantiating his claims. Mr. Blake took the matter up with the engineers of the Surface Combustion Company, but the test data failed to put in an appearance.

I will refrain from drawing any conclusions regarding their failure to furnish test data, but, before his paper is published, I think Mr. Blake owes it to this Society to produce the results of tests.

The paper says nothing about the difficulties which arise from variation in the heat value of the fuel gas. Producer gas is the standard fuel gas of steel plants, and its calorific value fluctuates considerably, depending upon the whims of unskilled gas-house labor; and, if the heat value of the gas varies, even the best proportional mixer falls down on the job.

Mr. A. E. Blake: Replying to Prof. Trinks's interesting discussion, I will treat a paragraph at a time.

It is undoubtedly true that since gas has been used as fuel, use has been made of appliances which permitted or promoted the formation of gas-air mixtures capable of supporting combus-

tion. Very many burners which are sold at the present time are said to accomplish this and they are simply constructed of pipe fittings and are inexpensive. A common feature, however, is independent control over the air and the gas. At this point I will insert a portion of a foot-note from one of the articles that Prof. Trinks has contributed to the *Blast Furnace and Steel Plant*.*

"The length of flame depends upon the design of burner and upon the mixing of fuel and air at the point of leaving the burner. In the case in question, the fuel is natural gas, and each burner consists of a gas pipe in an air pipe. The so-called theoretical flame temperature, based upon instantaneous combustion, is 3,500 degrees F., while the actual flame temperature probably does not exceed 2,600 to 2,650 degrees. But in the actual flame the hydrogen burns first, bringing the carbon up to incandescent heat, and radiating the latter to the surroundings. The carbon burns gradually in the measure as it finds oxygen, and maintains the temperature of the flame at a fairly constant level. In open hearth furnaces the mixing of gas and air is quite imperfect, and flames of 20 feet length can be observed with natural gas fuel."

This foot-note seems to indicate clearly the advantages which are to be gained by speeding up combustion, especially if anyone happens to be using a 20-foot flame in a 10-foot furnace. Incidentally, the rule already mentioned as regards the rate of heat transfer between products of combustion and work being heated, comes to mind, and it is clear at once that by increasing the temperature difference, we increase the rate of heat transfer.

I do not recall having seen any radiant piles of stones in industrial furnaces in the Pittsburgh district. It has been customary to use pins, stilts, balls, and many other shapes in clay and porcelain in domestic heating appliances, however, and they serve admirably to bring home to us all the remarkable qualities of incandescent radiation. Another instance known to us all is the Welsbach gas mantle. There is much about the operation of these and other fixtures to justify us in claiming that surface combustion is unwittingly practiced by their use. We all must realize, therefore, how ridiculous any patent claims would look in this connection. Those who have commercialized surface

*Oct. 1919, p. 490.

combustion have had the foresight to patent certain methods of application hitherto not known or practiced—as evidenced by the granting of patents—and certain types of apparatus found to have merit for the purposes intended. I recall that only quite recently, at the behest of a patent attorney, a certain concern stopped its illegal use of a refractory bed.

If the reader will examine paragraphs three and four, to which allusion has been made, it will be apparent that the objection which has been raised is not in point. If by the term "rate of combustion" Prof. Trinks means merely the rate at which a mixture of gas molecules will absorb sufficient kinetic energy to cause destructive collisions and, therefore, enable occurrence of the chemical rearrangement by which flue-gases are formed, I must say that he is in error. This absorption of energy takes place in the mixture during the quite finite interval of time required for it to travel from the discharge orifice to the zone of reaction, wherever it may be. In the zone, the speed of reaction is of the "molecular dimensions" referred to. If incandescent bodies can radiate additional energy beyond that otherwise supplied to the gases, the zone of reaction will recede by so much toward the orifice. It remains only to emphasize the fact that combustion cannot possibly occur until the requisite amount of energy has been received by the gases. The hotter they are at the beginning of operations, the more quickly they may arrive at the combustion stage. The rate of combustion, therefore, is only the rate of chemical combinations, when the term is applied to molecular reaction. In order to express the matter more clearly in the paper, I have inserted the phrase, "combustion propagation," or its equivalent.

In reply to Prof. Trinks's next paragraph, I will quote once more from his articles in the *Blast Furnace and Steel Plant*.*

"In numerous tests which I have made with ejectors, inducting either fuel or air, I found that it is extremely difficult, if not impossible, to maintain a constant gas to air ratio over a wide range of flow, and with varying back pressure, arising either from manipulation of flue dampers or from pressure head caused by friction of gas-and-air-mixture. . . .

"In connection with the subject of premixing burners mention should

*Nov. 1919, pp. 541–542.

be made of the most of premixing burners with independent adjustments for the flow of gas and of air. An example from the multitude of these burners is shown in Fig. 79 and 79a (Tate-Jones Type). The successful use of any one of these burners requires the services of an ever watchful and experienced fireman who can tell from the appearance and from the color of the flame whether or not he is operating with the correct air to gas ratio. Reputable firms know the limitations of this type of burner, but month after month inventors bob up with new types of premixing gas burners that 'get more heat out of the gas than there is in it.' As a rule it is quite difficult to convince them of the fallacy of their ideas."

I trust that he will be willing to believe that the efforts of others have, by chance, been more successful than his own, and I am glad that he seems to consider automatic proportioners to be desirable.

As Prof. Trinks has observed, one must indeed be careful when it comes to heating steel. In melting glass and metals, and in similar work, the argument to which he has called attention does not apply, but there is certainly need for cautioning users of surface combustion methods in certain cases. Possibly the discussion by Mr. Mitchell will be of assistance in showing whether the danger can be overcome, and the subsequent remarks by Mr. Bradshaw, with my reply will also be of value.

Incidentally, I might include the following quotation from Prof. Trinks's article in the *Blast Furnace and Steel Plant*.*

"Turning first to the consideration of proper heating, we readily see that it involves uniformity of temperature with regard to space, controllability of temperature with regard to time, and freedom from chemical reaction between flame and stock (material being heated). The higher the furnace temperature, the easier it is to maintain space uniformity of temperature, because at high temperatures even small temperature differences cause vast differences of radiant energy which result in speedy temperature equalization. In high temperature work (2,200 deg.), heat transmission into the surface of the steel is much more readily obtained than heat penetration within the steel. For that reason furnaces of the combustion type are very satisfactory for high temperature work in spite of their tendency to localize the heat."

It is difficult to overemphasize the importance of treating every problem upon its merits and this serves to show the rela-

*Jan. 1920, p. 118.

tion of the engineer to furnace design and operations, and the necessity of bringing all possible training, experience, and common-sense to bear upon problems like these. I know of no person or organization which is infallible along these lines and trust none of the foregoing will be misconstrued.

The observations concerning the paragraphs used to compare furnace conditions imposed by surface combustion with those which obtain in ordinary heating are very true.

References to the portion relating to excess air are also true. Prof. Trinks undoubtedly has in mind the burners mentioned in the quoted portions of his articles.

I regret that a supply of copies of Fig. 5 was not available when the advance copies were mailed, but I feel that Prof. Trinks's knowledge of the tunnel type of burner is such that he was not handicapped in preparing his very fine discussion. I trust he will read once more the statements which are intended to show the precise function of these tunnels. One must realize that prevention of blow-off and acceleration of combustion by radiation influences are both very desirable.

Prof. Trinks's reference to his attempts to gather data from the writer as to the range of automatic proportioning for the apparatus I have described is quite interesting. He did make earnest appeals for the data referred to, and I did seek to obtain some, but received the report "busy" from the other end of the line. However, I did the best I could and sent to him reprints of some of the papers mentioned in the bibliography, and some of the information he requested was checked so that it would not be overlooked. I also supplied him with copies of cuts from a technical journal illustrating in cross-section both the high-pressure and low-pressure systems. To my surprise and disappointment I saw, upon the publication of the November, 1919, issue of the *Blast Furnace and Steel Plant*, that only the low-pressure system was shown, and that it had been carelessly mistaken for the high-pressure system and so described in the accompanying discussion. This discussion does not apply accurately to the high-pressure system. Furthermore, the illustrations supplied happened to show the type of burner for which a refractory bed is necessary, and the bed and its location with respect to the work-

ing hearth were shown. Unfortunately, Prof. Trinks published only part of the illustration, completely omitting the refractory bed and the hearth. Anyone looking at the illustration as it appears would see at once that the burner would be inoperative.

When Prof. Trinks's attention was called to the matter, he regretted to learn that he had mistaken the two systems, and I found it necessary to point out that the figure used provided for an air supply, and gas at reduced pressure. He had assigned a pressure of 15 pounds per square inch for natural gas for the system he had supposed to be high pressure. Pure natural gas, by the way, would require about 40 pounds. In a reprint of the article by Prof. Trinks, he very kindly accepted the writer's suggested phraseology to describe the system shown, but further persisted in a mild way in maintaining that variations in barometric pressure could vary the air-gas ratio by as much as five per cent. I hope we may never be visited by any such atmospheric disturbance as would be necessary to cause the amount of variation suggested. The portion of the figure which had been eliminated was not replaced. Shortly after this episode, Prof. Trinks wished to receive more material and data which he might publish, and since I deeply appreciated his altruism (He is a consulting engineer for the Tate-Jones Co., Inc.), I wrote for the information, though I hardly expected it might be forthcoming. It did not come, as he has remarked. However, in order to oblige him, and to restore his confidence in the apparatus, I submit the following test record secured some years since during the ordinary operation of an oil still. These tables show results of tests of the same furnace:

TABLE I

SPECIAL BLAST BURNERS WITH TWO-VALVE CONTROL

Time	Cu. ft. per hour	CO_2	O_2	CO
2.00	293	8.8	10.2	0
3.20	218	12.2	8.6	0
4.00	255	13.2	3.2	0
*5.00	360	15.2	.2	0

*This condition could be maintained only long enough to get a gas sample. Test run by gas company expert.

TABLE II

FIRED BY CORRECTLY DESIGNED AND PROPORTIONING INSPIRATOR

Time	Cu. ft. per hour	CO_2	O_2	CO
9.50	700	15.8	0.3	0.0
1.43	225	15.5	0.0	0.5
2.05	355	15.8	0.0	0.2
3.10	249	15.4	0.0	0.1
3.52	271	16.0	0.0	0.0
4.15	235	15.6	0.2	0.0
5.15	260	15.4	0.6	0.0
6.15	300	15.4	0.7	0.0
7.15	260	15.7	0.3	0.0
9.15	280	15.4	0.8	0.0
10.45	280	15.9	0.5	0.0

It can be said in extenuation of my lack of test data that it is so easy a matter to adjust the proportioners to produce the desired atmospheric condition, that these analyses are seldom called for. Possibly the preceding references to neutral flue-gas furnaces will prove of interest.

On the subject of variation in the quality of gas there is much to be said. From reports which I have secured, I am of the impression that the quality of artificial gas supplied by public service corporations is very constant. I am told also that proper operation of coke-ovens in steel plants will insure gas of constant composition. There are rumors of variable natural gas supply, but no trouble has been reported to me on that score except during the winter shortages which require no explanation before this Society. For practical purposes, a variation of ±10 B.t.u. in any of the gases fairly free from inert material is of very small consequence. Prof. Trinks probably has producer gas in mind in bringing up the subject, and I am glad to say that the hand-poked producer seems to be growing more and more antiquated. Producers are bound to become less and less fashionable, with increased local knowledge of the possibilities of water-gas, mixed water-gas and coke-oven gas, and other gases virtually free from inert material. A discussion of the comparative merits of water-gas and producer gas appeared in connection with Prof. Fred. Crabtree's paper before the Society, on "Some Considerations with Regard to Fuel Gas."*

*"Proceedings," April 1919, p. 117.

GRINDING WHEELS; THEIR MANUFACTURE, USES IN INDUSTRY, AND FACTORS AFFECTING THEIR SELECTION

By Wallace T. Montague*

Grinding is one of the most ancient of arts. Prehistoric man shaped his instruments of stone and later of metal by rubbing them on rocks which possessed abrasive qualities. It is not a matter of record when the idea of cutting out a circular block of stone, mounting it on a spindle, and revolving it by hand was first thought of.

Sandstones were originally used in the industries where grinding operations were performed, although the applicability of emery was generally recognized by the Greeks of the early ages, who found it on the island of Naxos. The extensive use of emery in competition with the sandstone was limited until around the year 1870, when a method was invented for binding the grains together with a suitable medium and forming the wheels into necessary shapes for use in grinding.

Improvements in the methods of manufacture of grinding wheels naturally included a betterment of the abrasive material, with the result that the artificial abrasive was developed to overcome the imperfections of the natural emery, and to make available an abrasive in sufficient quantity to meet the ever increasing needs of industry.

Abrasives. In general, there are two types of abrasive—aluminous, and silicon carbid, the former consisting essentially of aluminum oxid, and the latter of a chemical union of the elements carbon and silicon.

Aluminous abrasives occur in nature as minerals in the form of emery and corundum. Aluminous abrasives are also manufactured by electric furnace methods and sold under the trade names "alundum," "aloxite," "borolon," etc.

*Assistant Sales Manager, Norton Co., Worcester, Mass.

Fig. 1. Bauxite Mine Where Crude Material Is Obtained for Making Alundum Abrasive.

Silicon carbid abrasives do not occur in nature but are manufactured in the electric furnace and sold under such trade names as "crystolon," "carborundum," "carbolon."

The Norton brand of aluminous abrasive, alundum, is made from the natural mineral, bauxite, containing as high a percentage of aluminum oxid as it is possible to obtain. The ore is carefully analyzed and a mixture so made that the product of the furnace operation is fully controlled. The mixture is fused in an electric furnace of the arc type, and during fusion the material is purified and changed from soft bauxite into hard crystals of aluminum oxid.

The Norton brand of silicon carbid abrasive, crystolon, is manufactured by heating pure silica sand and coke together in a special resistance type of electric furnace. The material is not fused, but a chemical reaction results from the high temperature employed, with resulting crystals of abrasive.

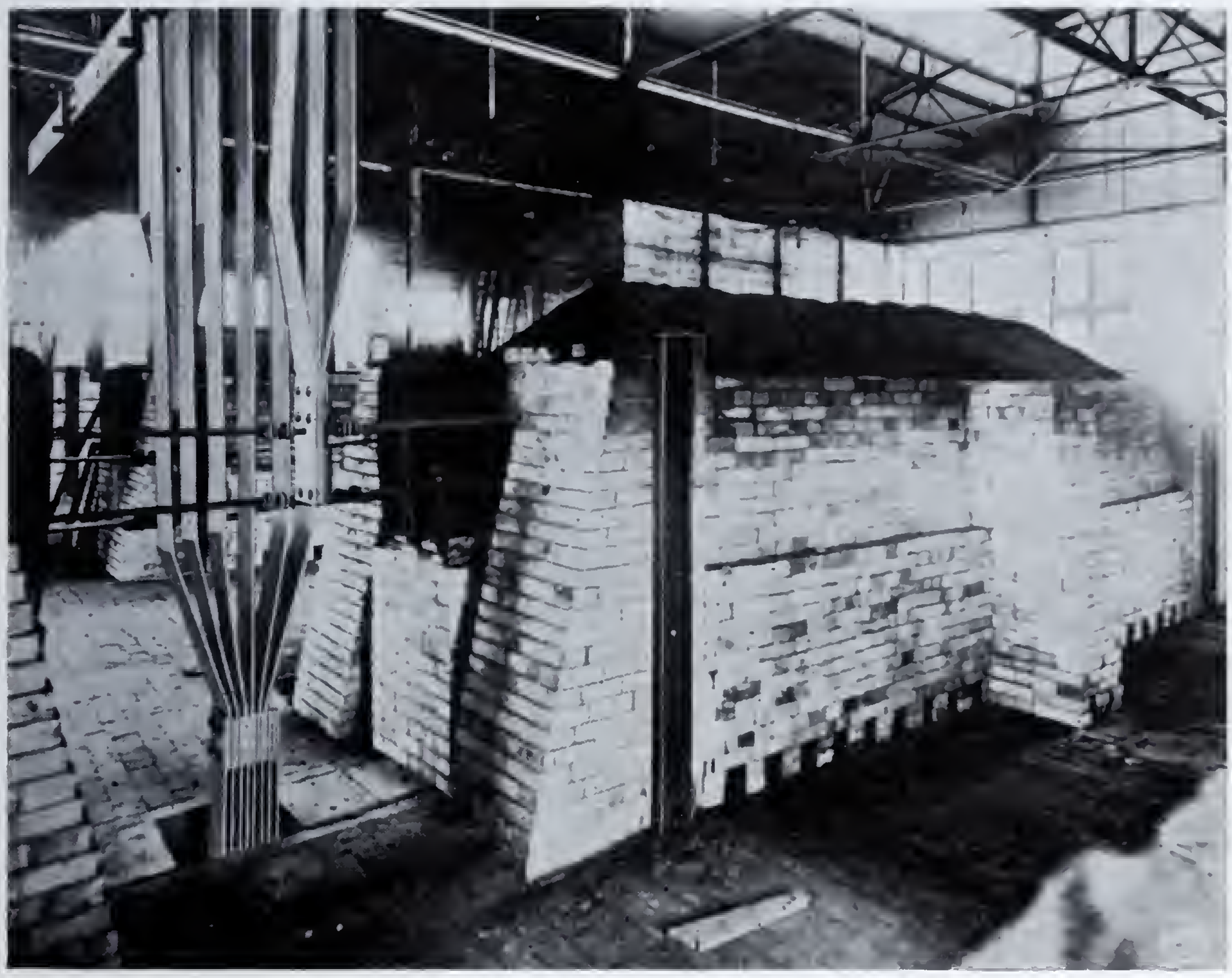

Fig. 2. Crystolon Furnace Ready to Turn on the Current.

Sizing the Abrasive. The alundum and crystolon abrasives are received at the Norton grinding wheel plant in irregular pieces about six inches in diameter. This material is passed through a series of jaw crushers, rolls, washers, etc., and is finally sized by being passed through standard mesh screens. The standard grain sizes begin at 8 mesh and continue through 200. The flour which is left, is designated as 200-F, and is further refined and classified by hydraulic means into such sizes as F, 2F, 3F, XF, etc. The number giving the size of the grain indicates approximately the number of holes to the linear inch in the screen through which the grain will just pass. For instance, a 30 grain will just pass through a screen having 30 small holes to the linear inch or 900 small holes to the square inch.

After passing over the sizing screen, the abrasive grain is stored in tanks, ready to be sent out as a polishing material or to be used in the manufacture of grinding wheels.

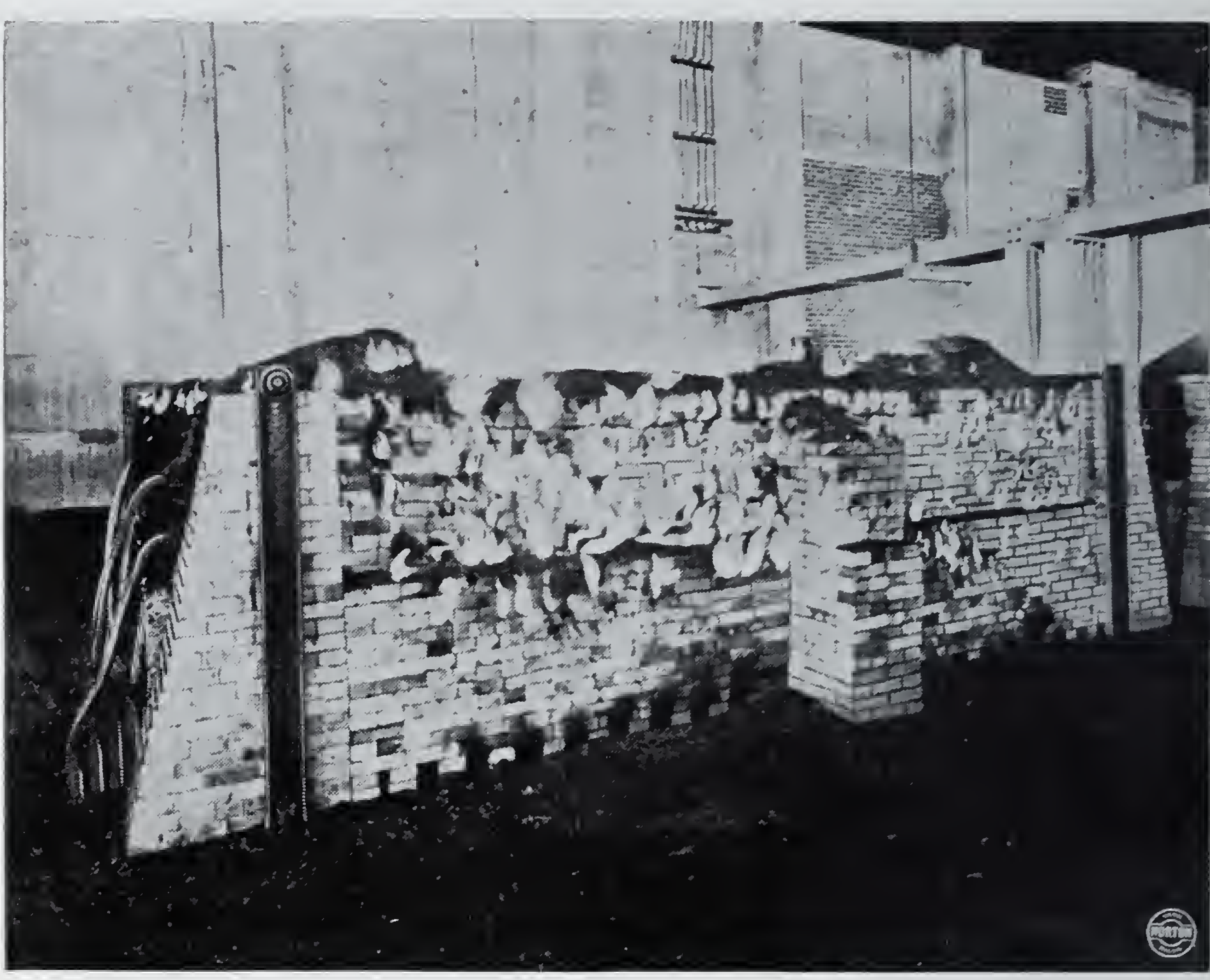

Fig. 3. Crystolon Furnace Burning.

Manufacturing Processes. Grinding wheels are manufactured by four processes—vitrified, silicate, elastic and rubber.

By far the larger proportion of grinding wheels is manufactured by the vitrified process. In this process, the abrasive grain is mixed with the proper amounts of clay and water until the mixture has the consistency of a mud, which can be easily poured into molds. After pouring into molds, the wheels are taken to drying rooms and left until they are thoroughly dry. They are then shaved on special shaving machines to the approximate shapes and dimensions required, and placed in dry storage, ready to go into the kilns for vitrification. Vitrification in the kilns takes place at about the melting point of steel and the length of time required for heating, the length of time held at high heat, and the cooling period are very important. Kilns are of the type used in the pottery industry, and are fired by a series of hard-coal fires uniformly spaced around the base of the kilns. In the larger types of kilns, it is approximately three weeks from the

Fig. 4. Cooling Floor Showing Alundum Furnaces In Background.

time the kiln is charged, until it is drawn. This time is absolutely necessary, and regardless of the emergency nature of any order, every wheel burned in the large kilns must remain there for the full time. After the wheels have been burned, they are sent to machines where they are shaped to exact size by means of hard metal cutters.

Silicate wheels, as the name indicates, are made by using a bonding material composed of silicate of soda. These wheels are made by tamping into iron molds, and they are baked at a comparatively low temperature. By this process, all wheels 30 or more inches in diameter are manufactured, 60 inches in diameter being the maximum size that can be made.

Elastic wheels are made by using a bond having quite a degree of elasticity. The bond is of an organic nature and is composed mostly of shellac. These wheels are also tamped into iron molds and are baked at a comparatively low temperature.

Rubber wheels are made by mixing abrasive with rubber, and later, vulcanizing the resultant product.

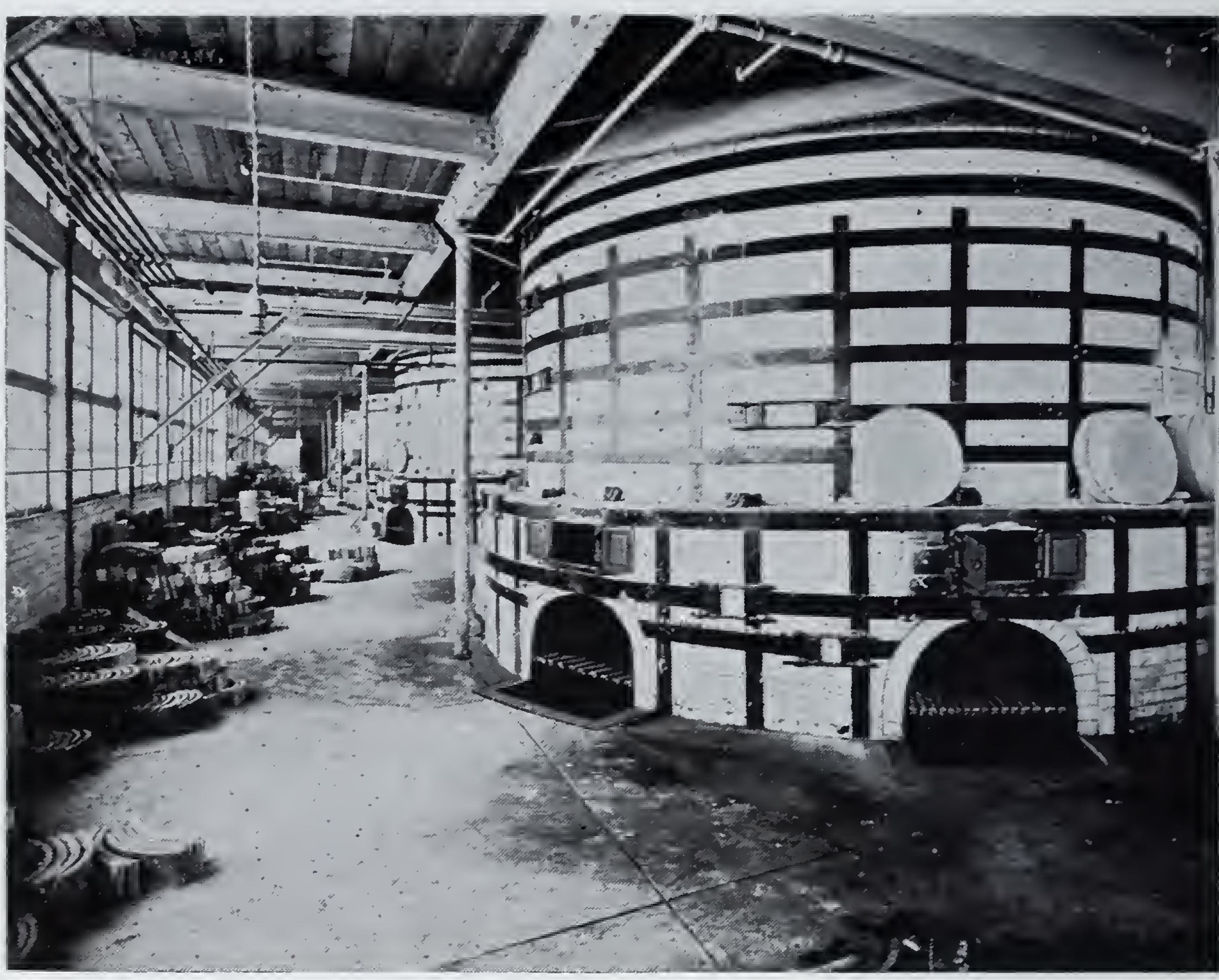

Fig. 5. View in Norton Company's Plant Showing Exterior of Kilns.

Silicate wheels are used largely in the cutlery industry in general to replace sandstone; and for all wheels over 30 inches in diameter, which cannot be manufactured commercially by the vitrified process. Elastic wheels are used where very thin wheels are required for cutting off stock; also for finish grinding of chilled iron rolls, and for other work where a fine finish is desired. Rubber wheels are used on the same type of work as elastic wheels, except that they have a somewhat harder action and are, therefore, used only where grades harder than those made by the electric process are required.

Abrasive Action. The abrasive action of an aluminous abrasive is dependent upon the amount of crystalline aluminous oxid present and also upon the temper or brittleness of the abrasive.

The best grade of emery comes from Turkey. It contains up to about 65 per cent. of corundum, which is the form in which the cutting element occurs in emery. Emery mined in America

has as low as 10 per cent. corundum. The chief impurity of emery is magnetic iron oxid. Alundum abrasives contain more than 92 per cent. of this cutting element, and a special alundum known as No. 38 contains more than 98 per cent. aluminum oxid. Practically no magnetic iron oxid is present in these abrasives.

Artificial aluminous abrasives are more efficient than emery, because: (1) they contain a much higher percentage of cutting element; (2) being free from impurities, they are capable of variations in toughness to suit the work to be done; (3) they are made to a definite standard of composition and temper.

The grinding wheel to meet present day requirements must be a scientifically developed cutting tool. Its action when at work is similar to that of the steel milling-cutter. On the face of the wheel are millions of cutting teeth at work every minute, and although these teeth are not as long or as strong as the teeth of the steel cutter, and cannot cut as deep, they are capable of working at a much greater speed. Each little cutting tool, which in substance is a grain of abrasive material, cuts off a chip at each revolution. The chips resemble, in shape and character, the chips cut off by the milling-cutter.

Uses in Industry. The uses of grinding wheels in industry to-day are many and varied. The great refinement attained in the case of the gasoline motor used for automobiles could not have been reached without the use of the grinding wheel and artificial abrasives. Likewise, the grinding wheel plays an important part in the manufacture of tractors, motor trucks, gas-engines used for farm purposes, etc.

The ball- and roller-bearing industry, which has grown up alongside the automobile industry, is likewise absolutely dependent upon artificial abrasives for the refinement and accuracy of its product. Being composed of hardened alloy steels, the only way that these could be brought within the required limits of accuracy and finish is by means of such aluminous abrasives as alundum. Likewise, the requirements of this industry are so great that existing supplies of natural abrasives even though they were of proper standards of purity, would not begin to meet the demand.

The phonograph, the typewriter, the adding machine, the cash register and other apparatus of similar nature could not be made as economically to-day, if it were not for the grinding wheel industry and artificial abrasives. The agricultural implement industry uses grinding wheels and abrasive grain in large quantities for the manufacture of harvesting and threshing machinery, plows, planters, etc. Even such activities as the textile industry require grinding wheels for sharpening cards, snagging castings, and maintaining tools, cutters and dies used extensively in keeping up its equipment.

The leather and shoe industry uses grinding wheels for the buffing of hides and for the sharpening of leather cutting and shaving knives.

The steel-mills use alundum grinding wheels for grinding out seams of high-speed steel billets preparatory to rolling into bar stock. The steel foundries use alundum wheels for snagging steel castings. Crystolon grinding wheels are used in foundries for snagging cast-iron castings, and for cleaning castings of brass, bronze and aluminum.

The railroad industry has extensive use for wheels composed of artificial abrasives. Such parts as locomotive piston-rods and valves must be ground on cylindrical grinding machines; guide bars must be surface ground with alundum grinding wheels; steel car-wheel treads and flanges sometimes are ground with alundum wheels, and manganese-steel frogs and switches have to be surfaced and fitted with grinding wheels composed of aluminous abrasive.

The optical industry uses aluminous abrasive wheels for lens grinding, and aluminous abrasive grain for roughing out lens blanks prior to polishing.

The cut-glass industry employs the artificial grinding wheel to a very large extent in cutting the intricate designs that go to make up the beauty of this ware.

The marble industry employs silicon carbid abrasives in thin wheels for sawing marble into slabs, and in thick wheels for surfacing or molding the marble into various shapes and designs.

The final polish on marble slabs used in interior building operations is obtained by means of abrasive blocks composed of

very fine grit silicon carbid or alundum abrasive, followed by putty powder.

Selection of Wheels. The main points to consider in the selection of grinding wheels are as follows:

Material.
- High tensile strength. (Aluminous abrasive.)
- Low tensile strength. (Carbid of silicon abrasive.)

Operation.
- Cylindrical.
- Surfacing.
- Internal.
- Sharpening.
- Off-hand grinding.
  - Bench stands.
  - Floor stands.
  - Swing frames.
  - Portable.
    - Electric.
    - Pneumatic.
    - Flexible shaft.

Wheel speed.
Work speed.
Contact.
Condition and type of grinding machine.
Personal factor.

Material. Whenever a grinding job is presented to you, the first thing to think of is the nature of the material to be ground—whether it is hard or soft, etc. If it falls under the general head of a high tensile-strength material—such as all steels and down as far as the hard grades of bronzes—then an alundum wheel of some kind should be used. If, on the other hand, the material falls in the class of low tensile-strength materials—such as cast-iron, chilled iron, brass, soft bronzes, aluminum and copper—then you should use crystolon wheels.

Operation. The next thing to consider is the nature of the operation to be performed by grinding; that is, whether cylindrical, surface, internal, sharpening, or off-hand grinding is demanded. There are so many small points to be considered in connection with each operation that it is impossible to go into this in detail.

Wheel Speed. Wheel speed should be considered, but with any given class of grinding it is more or less fixed. We recommend the following speeds for different classes of grinding:

Application	*Speed in feet per minute*
Cylindrical grinding	5500 to 6500
Snagging and general off-hand grinding on bench and floor stands	5000 to 6000
Surface grinding	4000 to 5000
Knife grinding	3500 to 4000
Hemming cylinders	2100 to 2400
Wet tool grinders	4000 to 5000
Vertical surface grinding machines	4000 to 4500
Elastic and rubber cut-off wheels	9000 to 12000

If the speeds deviate very much from these, and it is impossible to change them to suit our recommendations, then this must be taken into account in your recommendations. Speeds higher than those recommended call for slightly softer grades to offset the harder cutting action; and speeds lower than those recommended call for slightly harder grades than would be ordinarily supplied.

Work Speed. It is impossible to tell a customer the exact speed at which his work should be done on any given grinding job. It is largely a matter of experiment. The work speed should be suited to the wheel in use and the nature of the material to be ground. On the Norton cylindrical grinder, a speed of from 60 to 80 surface feet per minute is often used for roughing and from 30 to 40 surface feet per minute for finishing. On most types of precision grinding machines, it is customary to rough grind at a higher surface speed of work than on finish grinding.

Fig. 6. View in Norton Company's Stock Rooms Showing Racks for Storing Wheels.

Contact. Contact affects grade selection. Broad contact calls for softer grades and narrow contact for harder grades, as the case may be. This is especially true in snagging and offhand grinding. Where wheels are used for grinding the burr left by welding, or for grinding sharp fins from castings, extremely hard grades, such as S, T and U, are called for. In cylindrical grinding, the contact varies with the diameter of the wheel and the work, increasing with larger work or with a larger wheel, and thus making a softer grade of wheel desirable.

Condition of Grinding Machine. This is something which you would really have to observe personally in order to understand how it would affect grinding wheel selection. If the spindle is loose and cannot be put in good condition, a harder grade of wheel must be used than would ordinarily be recommended. This is in order to overcome the tendency to pound the wheel face

to pieces. Light, flimsy machines and machines improperly secured to the foundation also call for harder grades than would ordinarily be used. Machines are frequently placed in the middle of a wooden floor which vibrates badly and in this case harder wheels must be used than for a machine on a firm, solid foundation.

Personal Factor. This is extremely important in the operation of grinding wheels, frequently influencing the results obtained as much as 100 per cent. We mean by this that different men working on the same kind of machines and on the same work in the same shop will get one result, say 15 hours life, whereas other men under exactly the same conditions might get 30 hours. This is based on records obtained and not on impressions, and explains why the same wheels will work differently in different shops.

DISCUSSION

Mr. E. C. Brandt:* How do you determine what is the proper lubricant to use with different grades of abrasive?

Mr. Wallace T. Montague: Lubricants used to-day are more or less standard, being either water with a little soda in it to keep from rusting the grinding machines; or a special compound containing a little oil; or a combination of mineral lard oil and soda water. The determination of the compound largely depends upon the nature of the operation. If you are doing a fine precision job, I should suggest a compound containing a little oil, but if you are simply grinding rough work and you have to use a lubricant to keep the work cool and the wheel free, I think soda water is good enough.

The chief function of the lubricant, in precision grinding at least, is to maintain a uniform temperature of the work. Whether it is hot or cold makes little difference, although it is important to see that the temperature of the work is uniform.

Mr. E. C. Brandt: If pure oil were used, would it not have a tendency to fill the wheel at all times and cause more or less trouble? It has occurred to me that, due to the heat and sparks caused by the grinding operation, a special oil with a very low flash-point would have to be used.

Mr. Wallace T. Montague: If a thick, heavy oil were used, it certainly would have a tendency to fill the wheel, produce what we term glazing, and cause a great deal of difficulty, with a resulting loss in cutting qualities of the wheel. It is doubtful if the question of flash-point would make any difference, because we have never had any difficulty from sparks setting fire to oil, except in one or two instances where clear kerosene was used for the grinding of aluminum.

*Supervisor of Equipment and Methods, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Mr. A. E. Blake:* I would like to ask whether either of these abrasives, alundum or crystolon, have been tried out in work on plate-glass.

Mr. Wallace T. Montague: Yes, but do you refer to their use in wheels or as loose grain?

Mr. A. E. Blake: Either way.

Mr. Wallace T. Montague: We have not been entirely successful in beveling plate-glass with a solid grinding wheel. We have not been able entirely to eliminate the scratches, which come from grains that become detached from the wheel. With sandstones, which are used extensively for beveling plate-glass, the loose grain gets more or less pulverized between the wheel and the glass; that is, it "muds down," as they say. With artificial abrasives, the grain remains solid and makes a scratch in the glass. At a large plate-glass works near here, I believe they are able to use alundum grain for the second operation. They cannot get a polish with it, there is so much cut to the abrasive, but it removes material rapidly on roughing or semi-finishing operations.

Mr. E. C. Brandt: What experience have you had in grinding copper?

Mr. Wallace T. Montague: In general, a very disagreeable experience. Copper can be ground, but only with a very soft, free-cutting wheel and plenty of lubricant to keep the copper from softening under heat. Either an alundum or cystolon grinding wheel should be used, in comparatively soft grade, and the finish would have to be obtained chiefly by frequent dressing of the wheel just as smoothly as possible before taking the final finishing cut. That has been our experience, in general, on precision grinding.

Mr. E. C. Brandt: Did you ever try dipping or rubbing a wheel in paraffin?

*Sales Engineer, Surface Combustion Co., Pittsburgh.

Mr. Wallace T. Montague: Yes, and it helps a lot. We have filled wheels with paraffin at the factory. The difficulty with this was that frequently when we shipped them, they got up against steam pipes or came in contact with sufficient heat to permit the paraffin to run out, in places; but for off-hand grinding jobs, especially, we think the use of tallow or paraffin rubbed on the face of the wheel by the operator, or dipping the wheel in paraffin, has a beneficial effect, in that it prevents excessive loading.

Mr. W. B. Spellmire:* When you speak of crystolon and carborundum, do you mean carbid of silicon?

Mr. Wallace T. Montague: Yes, these are trade names, carborundum and cystolon being really the same product, chemically—silicon carbid. It formerly cost $200 or $300 an ounce, and was used by jewelers for lapping gems in place of diamond dust.

Mr. W. B. Spellmire: It was discovered in the laboratory in attempting to make artificial diamonds, was it not?

Mr. Wallace T. Montague: Yes, I believe so.

Mr. E. C. Brandt: What would you do in case you were asked to make a wheel of the ring type, 60 inches in diameter?

Mr. Wallace T. Montague: We would make it. We can make wheels as large as that by the silicate process.

Mr. E. C. Brandt: Suppose this were a ring wheel with 2½-inch face about six inches wide?

Mr. Wallace T. Montague: We could not make it. The rim is too narrow for the large diameter of the wheel.

Mr. E. C. Brandt: I am connected with a situation where the proposition requires a wheel 54 inches in diameter with a 2-inch rim. It is made of segments or blocks of abrasive, and

*Manager, General Electric Co., Pittsburgh.

it takes 24 of these blocks to make each rim complete, and blocks are made on radii to suit the rim of the chuck. There are one-inch spaces between these abrasive blocks to allow clearance for the lubricant to wash out the abrasive and chips.

Mr. Wallace T. Montague: That is a new development which is very interesting. We have not made solid-ring wheels of that large size and narrow rim. The problem you discuss is a development of the Diamond Machine Company, which is perhaps going to take the place of some milling operations. I will know more about this to-morrow, after I have been out there.

Mr. W. B. Spellmire: The speaker has shown a picture of Niagara Falls as illustrating the low cost of power from hydro-electric development. In 1912, the United States Commissioner of Corporations submitted a report on "Water-Power Development in the United States,"* which, I believe, showed conclusively that the selling price of power was not fixed by the possible low cost of hydro-electric development, but rather fixed by the cost of coal. Obviously, there is no reason why a hydro-electric company should sell its power at any appreciable amount below the cost of generating the same power by coal. It is probable that with the very high thermal efficiency of large turbo-generators, and with relatively cheap fuel and water available, electric enery can be generated to-day at a cost lower than with hydro-electric developments previously recorded as quite economical. The chief merit of the hydro-electric development is that fuel is not consumed, thus promoting the conservation of our natural resources.

Mr. Wallace T. Montague: Perhaps the chief argument, then, for using Niagara power is that it is an economic gain to do so.

Mr. W. C. Hawley, *President*: Are there any further questions? If not, Mr. Montague, we wish to express to you our appreciation of your kindness in presenting this paper, and to tell you how much we have enjoyed it.

*U. S. Bureau of Corporations, Washington.

WASTE HEAT BOILERS

By D. S. Jacobus* and Arthur D. Pratt†

In the earlier practice with waste heat boilers it was the custom to minimize the frictional resistance of the gases flowing through the boiler by providing a large flow space, in order to interfere as little as possible with the draft leaving the industrial furnace, such as a copper smelting furnace, which supplied the waste heat. This practice limited the field of application of waste heat boilers. To show the progress in the art we will deal with the modern practice of our own particular company, in which a boiler is provided having a high draft resistance and in which the baffling is arranged to give a relatively small area of flow space through the passes so as greatly to increase the velocity of the gases. A suction fan is used to overcome the higher draft loss due to the increase in velocity of the gases, and the heating surface of the boiler is arranged in series in such a manner that in connection with the added draft loss under the increased velocity the desired draft will be afforded at the outlet of the furnace supplying the waste heat as well as at the outlet of the boiler.

The total capacity of waste heat boilers, built in accordance with our modern design, which we have installed during the past seven or eight years in various classes of waste heat work is over 150,000 rated horse-power. The capacity these boilers are developing in terms of normal rating varies, of course, with gas weights and temperatures. A conservative figure would be 70 per cent. of normal rating, which is on a basis of ten square feet per horse-power, which would mean a total of 105,000 horse-power actually developed. In the ordinary plant where waste heat installations are made, the coal burned in direct fired boilers of various types, averaging the poor results with the good, will in all probability be at least four pounds per hour per horse-power developed. On the basis of 105,000 horse-power developed, four pounds of coal per hour per horse-power, 24 hours

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†Assistant Advisory Engineer, Babcock & Wilcox Co., New York.

operation, 300 days a year, the total annual saving in coal alone is over 1,500,000 tons. It can thus be seen that the saving effected by the use of these waste heat boilers is a decided factor in the conservation of the coal of the nation. Aside from the aspect of conservation, there is a large saving in money to the users of waste heat boilers with coal at its present price—or, for that matter, at any price. The return on the investment in this class of apparatus is such that the owners of any plant, where spent gases of sufficient volume and temperature are available, cannot afford to disregard the possibility of a waste heat installation.

While the term "waste heat" will in all probability continue to be used, it is obvious from the savings through its utilization, that it is a decided misnomer in many cases.

War conditions made it imperative to minimize the cost of fuel, and great credit is due to those who labored to promote a saving and to the users of fuel who co-operated to secure the saving that was effected. On account of the increase in the cost of fuel, the attention of the engineer is now turned more earnestly than ever to the problem. We should go further than we have in the past. With apparently unlimited resources, the dollars-and-cents side—obtained by balancing the interest on capital investment, etc., against the fuel saving—has been the controlling factor in deciding whether a more economical plant should be installed to take the place of one that is recognized as being wasteful. Eventually, we must consider the conservation of fuel for future generations and it may not be long before there will be laws with this in view.

The first installations of our modern design of waste heat boilers were made in connection with open-hearth steel furnaces. Certain minor difficulties of operation arose with those first installed, but these were no greater than were to be expected with a type of apparatus essentially new in that particular field, as well as different from the same class of apparatus in use in other fields of steam generation. That the initial difficulties of operation were overcome, is borne out by the fact that there are to-day in the United States over 210 open-hearth steel furnaces

equipped with such boilers, the total capacity of these furnaces being conservatively stated as 12,000,000 tons per year.

The steam engineer of to-day, while he is familiar with the use of waste heat boilers in one or possibly two classes of work, may not realize the widely varied classes of industrial plants in which waste heat boilers have been installed and are in successful operation. The tabulation following gives the different classes of industrial plants using our modern waste heat boilers:

Open-hearth steel furnaces.
Heating furnaces.
Cement kilns.
Dolomite kilns.
Copper refining furnaces.
Nickel refining furnaces.
Zinc refining furnaces.
Gas benches.
Glass tanks.
Oil stills.
Bee-hive coke-ovens.

The necessity for an increase in transfer rates in waste heat boilers, over that which exists in direct fired boilers to give results that are at all comparable, is perhaps not generally appreciated. In burning fuel under a boiler, a temperature is developed greatly in excess of the average waste gas temperature. For comparison of direct fired with waste heat practice, let us consider (1) a direct fired unit equipped with an underfeed stoker and (2) a waste heat boiler set, in connection with oil stills. In the former case, with proper stoker operation, the furnace temperature will approach 2700 degrees F., while in the latter case the temperature of the gases entering the boiler will be approximately 1000 degrees F.

In direct fired practice, a considerable proportion of the total heat absorbed by a boiler is absorbed through direct radiation to the tubes which are exposed to the radiant heat of the furnace. How great a proportion of the total absorption is accomplished in this manner is not ordinarily realized.

With a reasonably constant furnace temperature the *amount* of heat absorbed through direct radiation is, within reasonable

limits, a constant, irrespective of the capacity developed by an individual boiler. It naturally follows that, as the capacity of a direct fired boiler is increased, the *percentage* of total absorption through radiation is decreased, as this represents the ratio of the total number of heat units absorbed from the gases (which remains constant) divided by the total heat absorbed by the boiler (which increases with capacity). In comparing direct fired with waste heat installations it is necessary, because of the comparatively low ratings developed in the latter class of work, to consider the direct fired unit operating at a low capacity.

Experiment has shown that for a furnace temperature of 2700 degrees F. the absorption through direct radiation is, for a four-inch tube spaced on seven-inch centers, slightly over the equivalent of 80 pounds of water evaporated per hour from and at 212 degrees F. per lineal foot of tube exposed to direct radiant heat in the furnace—an absorption of some 77,630 B.t.u. per hour. In a 500-horse-power Babcock & Wilcox boiler, with the baffle arrangement ordinarily offered for underfeed stokers and with the boiler operating at its normal rated capacity, this evaporation, due to absorption through direct radiation, would represent approximately 66 per cent. of the total heat absorption.

The effect of absorption due to radiation varies approximately as the fourth power of the absolute temperature of the radiating medium. On the basis of an absorption through radiation equivalent to an evaporation of 80 pounds per hour from and at 212 degrees per lineal foot of tube in the furnace for a temperature of 2700 degrees F., the corresponding absorption for a furnace temperature of 1000 degrees in the case of the waste heat boiler would be approximately 3.65 pounds from and at 212 degrees per hour per lineal foot of tube exposed. If, for the sake of comparison, we assume that both the waste heat boiler and the direct fired unit develop their normal rated capacity, the absorption through direct radiation would be only three per cent. of the total absorption for the waste heat boiler as compared to 66 per cent. for the direct fired boiler. In a 500-horse-power direct fired boiler, operating at its normal rated capacity, the absorption through convection will then be equivalent to 170 horse-power. If the 500-horse-power waste heat boiler is to

develop its normal rated capacity, the absorption through convection must be equivalent to 485 horse-power.

The temperature of the gases leaving the radiant heat zone in the direct fired boiler will be somewhat higher than the temperature of the gases entering the waste heat boiler, the relative temperature with the direct fired unit and waste heat boiler both developing the rated capacity—approximately 1200 and 1000 degrees F., respectively. If the two units be operated at the same pressure, and the gases be cooled to the same ultimate temperature, we will have relative average temperature differences of approximately 460 and 360 degrees F. The total absorption through convection is represented, approximately, by the product of the transfer rate, the heating surface, and the range of temperature difference. To develop the above capacities through convection, it would be necessary to obtain transfer rates as follows:

Direct fired..........$R \times 5000 \times 460 = 170 \times 33{,}477$. $R = 2.47$.
Waste heat..........$R \times 5000 \times 360 = 485 \times 33{,}477$. $R = 7.02$.

In other words, if each of the two units is to develop its rated capacity, it would be necessary in the case of the waste heat boiler to arrange the heating surface in such a manner as to give a transfer rate more than three times as great as that in the direct fired unit. This comparison is an extreme case which has been used to indicate the necessity of high gas velocities where the gases are of a low temperature; conclusions should not be drawn from it respecting the effect of the absorption of radiant heat on the efficiency of a direct fired unit as other elements enter the problem.

The heat absorption, or heat transfer rate, is dependent upon the gas velocity and not upon the number of passes, except in so far as the number of passes affect the velocity. For equal gas weights, the velocity is the principal factor affecting the transfer rate; for, at any velocity so far used in modern waste heat work, the effect of the mean temperature difference of the gas and absorbing medium is slight as compared with the velocity. Naturally, for a given transfer rate, the greater the temperature difference the greater the total heat absorption, but the temper-

ature difference for the gas velocities employed has so slight an effect on the rate itself that any difference in the rate may be neglected.

First, assume the heating surface of a water-tube boiler with horizontally inclined tubes arranged to give the gases four passes over the tubes. If the boiler were, say, 18 tubes high, a gas particle would strike the tubes 4 × 18, or 72, times.

Again, take this same amount of surface arranged to give three passes of the gases in a boiler of a given width. In order to obtain the same gas velocity, and the heat transfer corresponding to such velocity in the three-pass unit, it would be necessary to reduce the length of the tubes 25 per cent. below that employed in the four-pass unit, and the equivalent amount of surface would be added in height. The three-pass unit would be 24 tubes high to give the same heating surface. In such a boiler, a gas particle would again strike the tubes 3 × 24, or 72, times.

Carrying the comparison to an extreme case, if the same amount of heating surface were arranged to give a single pass of the gases, still maintaining the same gas velocity and transfer rate resulting from such velocity, it would be necessary to shorten the tubes 75 per cent. This would result in a unit 72 tubes high, and a particle of gas would naturally strike the tubes 72 times as in the other cases. Such an arrangement of heating surface would, of course, be impracticable, but is described to indicate the principle involved.

The heat transfer rate would be the same for the three cases considered—that is, for four passes, three passes, or a single pass—whereas the frictional resistance to the flow of the gases, or the draft drop, would increase with any increase in the number of passes, on account of the added resistance due to changing the direction of flow of the gases in the different passes.

Because of the flexibility of design, through varying the arrangement and the amount of heating surface by changing the width and height of the boiler and the length of the tubes, it is theoretically possible to give the gases any desired number of passes over the heating surface and still maintain the gas velocity which will give the greatest commercial return. Under such conditions, the proper number of passes to employ in waste heat

work becomes a question depending upon commercial rather than engineering factors, and these should be given consideration in each specific installation.

There is the question of cost, though because of the relatively large return on the investment with this class of apparatus this is usually not of primary importance. A single-pass boiler without baffles is the simplest unit that can be offered. With a single-pass boiler, however, in order to maintain a velocity resulting in adequate transfer rates, it is ordinarily necessary to make use of short tubes; and this leads to a construction of relatively-high cost.

A second consideration in the proper number of passes to be offered is that of the point of removal of gases from the boiler setting. For any waste heat boiler where the gases enter beneath the tubes at a point corresponding to the furnace in ordinary direct fired practice, where the number of passes is made odd—that is, one, three, or five—the gases must be removed from the setting at or near the top of the boiler. Where the number of passes is even, the gases must be taken from the bottom and at the rear of the boiler.

The best arrangement to use, in most cases, is three passes. Where an overhead connection is desired, fan supports and platforms are provided. Where it is desired to place the fan and its drive on the floor, an easy connection can be made through the rear water circulators to the fan.

Economizers are frequently installed in connection with waste heat boilers. What we believe is a desirable—and certainly the most compact—arrangement of boiler and economizer, is a recently developed combination in which a three-pass boiler is used. The gases pass from the boiler, through the vertical, rear circulating tubes, directly into an economizer which is made up of horizontally inclined tubes extending transversely to the boiler setting. The gases pass downward over the economizer tubes while the water has an upward flow, a counterflow being obtained between the water and the gases, and the water in the economizer flowing continuously upward so as to avoid any pockets should steam be formed in the economizer. The fan location is at or near the floor line. The apparatus as a whole is much more compact than one in which the boiler, economizer, fan, and fan

drive are extended horizontally. Furthermore, the path of the gases over the economizer surface is downward, and experience has shown that with heavily dust laden gases it is much easier to keep the heating surface clean where the gases flow downward than where they flow upward. This advantage, which is an important one, is not possessed by an economizer where the flow of the gases is in a horizontal direction.

Draft is the most important factor in the determination of the proper number of passes to be offered in waste heat work. The draft loss through a water-tube boiler is a function of two factors—the loss due to frictional resistance to the gases in their passage over the tubes, and the loss due to the making of the turns over the baffles. In any upward pass of the gases there is a stack effect, due to the pass itself, which tends to offset the loss due to friction; and it is no uncommon occurrence in high-temperature, direct fired practice to find a greater draft suction at the bottom than at the top of an upward pass in a boiler. In a downward pass of the gases, on the other hand, there is a negative head to be overcome in addition to friction.

In order to recover the major portion of the power used for the fan drive through utilization of the heat in the exhaust, it is almost universal practice in waste heat work to use a steam-turbine drive for the induced draft fan. Experience has shown that with the gas velocities best adapted for this class of work, the exhaust from the fan turbine, when producing draft sufficient to overcome the total resistance through a properly designed three-pass boiler unit and giving the required draft at the outlet of the primary furnace, is just about the amount required to heat the feed-water entering the waste heat boiler to 212 degrees F. While the amount of heat recovered in this manner will, of course, vary with the gas temperature, the fan and turbine efficiency, and the class of primary furnace, the statement above may be accepted as generally correct.

Single-pass, waste heat boilers without any induced draft apparatus are the simplest that can be employed and, in fact, it is this design that was probably among the first of the water-tube boilers used in waste heat work. The early installations, how-

ever, were made of a low draft resistance in order not to interfere with the operation of the primary furnace.

There is a considerable field for the single-pass, natural-draft, waste heat boiler even under modern conditions. In plants where such boilers are applicable, the gas temperatures are high, approaching those of direct fired practice, and greatly in excess of the temperatures for which our modern design of waste heat boilers was developed. This statement is not to be taken as indicating that high gas temperature alone, without taking into consideration the other factors involved, makes the installation of a single-pass unit advisable, rather than a multiple-pass unit, but to indicate the limitation of the field of usefulness of the single-pass unit.

The single-pass unit can be successfully used only in connection with a furnace requiring a low draft. In some instances, such as in a puddling furnace, the heating surface can be so arranged that the boiler itself serves to some extent as a stack; and in serving as such the available draft from a given stack, although less than if no boiler were installed, will, when added to the stack effect of the boiler, provide enough draft for operating the furnace. If, on the other hand, we consider a primary furnace from which the gases emerge at low temperatures and which requires a greater amount of draft for proper operation—such as an open-hearth steel furnace—the cooling effect due to the installation of boiler heating surface, even in a single-pass unit of low gas velocity, would reduce the available draft to a point where the furnace operation would not be possible. In open-hearth steel practice, a draft of 1.5 to 1.7 inches is required at the checkers. Where no waste heat boiler is installed, with an available gas temperature of, say, 1100 to 1200 degrees F., a stack 160 to 175 feet high will produce the necessary draft. If, however, there is installed a waste heat boiler which would cool the gases to, say, 600 degrees F., the stack which would give 1.6 inches draft with a gas temperature of 1200 degrees F. would give probably less than 1 inch with a temperature of 600 degrees F., which would be too low for operating the furnace, even should a single-pass boiler be employed. If we allow a total draft loss, including the loss due to a single-pass unit, of 0.75 inch

between checkers and stack, the height in order to secure proper furnace operation would have to be about 400 feet. Under such conditions it is evident that with open-hearth and similar furnaces, waste heat boilers, either single- or multiple-pass, cannot be installed except in connection with induced draft.

A single-pass boiler may be used to advantage where a low weight of gas is available, as where the gas weight is small and the total corresponding return low the expense of an induced draft apparatus in addition to that of the boiler may not be warranted. This applies particularly to plants where, though the gas weights are low, the temperatures are high.

A single-pass rather than a multiple-pass boiler is sometimes the best to install in the case of an isolated plant where there is no outlet for the power developed except for use at the plant. In such a case, if the single-pass, natural-draft boiler will cool the gases to a point where the steam produced will meet the total requirements for the plant, there is obviously no necessity nor object in going to the expense of a more complicated multiple-pass unit with its induced draft apparatus. Naturally, in this case, the draft requirements of the primary furnace must be such that a single-pass, natural-draft unit may be satisfactorily installed.

There is a wide difference in the economizer problem in waste heat and in direct fired practice, on account of the widely different ratios of gas to water weights in the two classes of work. If we consider a waste heat unit utilizing low temperature gas, and a direct fired unit, both having the same heating surface and developing the same capacity, the ratio of the gas to the water weight in the case of the former is some four times as great as the same ratio in the latter case.

While special forms of economizers can be advantageously applied, which will operate properly when steam is formed in the economizer, in the ordinary form of economizer the temperature of the feed-water leaving the economizer must be kept below that due to the pressure at which the boiler is operated, under the extreme conditions that may occur in order to avoid steaming. If steam is formed in the economizer there will be a tendency to pass the water into the boiler in slugs, which would result in a

prohibitive variation in water level. Under such conditions, the water level in the boiler would rise when the steam is formed. The operator would naturally shut off the feed in an endeavor to prevent the water level in the boiler becoming too high, which would, for a time, increase the amount of steaming in the economizer. Eventually, when the water level in the boiler would fall, the economizer would be partly filled with steam, and during the time that the economizer was being filled no water would be passing to the boiler, which might cause trouble through low water in the boiler. Again, when steam is being made in the economizer, objectionable strains may be set up through heating the portions of the economizer which contain steam to a temperature in excess of that of the portions which contain water, and when water is again fed to the economizer and the steaming ceases, trouble may result from sudden cooling and from water-hammer. Obviously, under these conditions, it is necessary that the maximum temperature of feed leaving the economizer of the type considered shall be kept below the steaming temperature.

If a waste heat and a direct fired boiler having the same heating surface and developing the same capacity are equipped with the same amount and arrangement of economizer surface, the economizer fitted to the waste heat boiler will increase the temperature of feed more than the economizer fitted to the direct fired boiler. This is because of the higher ratio of gas to water weight in the case of the waste heat boiler as compared with the direct fired boiler.

Another condition that must be taken into consideration, and one which emphasizes the difference in the economizer problem for the two kinds of work, is that in direct fired practice any increase in the weight of water passing through the economizer—that is, an increase in the boiler capacity being developed—is ordinarily accompanied by a corresponding increase both in temperature and weight of gas entering the economizer; whereas, in waste heat practice, due to the possibility of irregularity in the operation of the primary furnace, there is no fixed relation between gas weight, water weight and gas temperature.

In view of the above, in order that the temperature of the feed-water leaving the economizer shall be kept below the steam-

ing point, the amount of economizer surface that can be installed in waste heat work is greatly below that which can be installed in direct fired practice. Furthermore, because of the possible irregularities of the operation of the primary furnace, the safe margin between the steam temperature and the temperature of the feed-water leaving the economizer must be made greater in the case of waste heat than in direct fired practice, where there is a more or less fixed relation between the functions determining economizer performance and where allowance may be more readily made for extreme conditions.

In general, in waste heat work, the economizer should be proportioned to add not in excess of 12 or 13 per cent. of the total heat absorbed by the boiler and economizer. Ordinarily, with low and moderate waste gas temperatures, this will result in an economizer which under normal conditions of operation will heat the feed to a point not closer than 60 degrees F. to the steaming temperature. While, of course, the amount of economizer surface necessary to give this result will vary with the gas weight and temperature conditions, in the average waste heat installation with entering gas temperature of from 1000 to 1500 degrees F. it will usually be from 30 to 35 per cent. of the boiler surface.

Though not strictly dealing with the recovery of waste heat, a development that may be considered in connection with water heating boilers, is the use of our modern waste heat boilers for direct fired practice. In the burning of a fuel under a boiler, if high furnace temperatures are developed and sufficient heating surface is exposed to radiant heat in the furnace, the absorption due to direct radiation is ordinarily a large proportion of the whole. To develop the same capacity from a given boiler, with fuels such as blast-furnace gas, where it is neither practicable nor possible to obtain high furnace temperatures, the amount of heat absorbed through convection compared to that absorbed through radiation must be greater than in the case of the high furnace temperature unit. In this case, it is advantageous to apply the principles of our modern waste heat boiler design.

While furnace temperatures of 2200 or 2300 degrees F. are theoretically obtainable with blast-furnace gas, it is probable that,

even with the best design of burners, the temperatures do not average over 2000 degrees F. with this furnace temperature, the absorption through radiation will be less than 40 per cent. of that absorbed through radiation with a furnace temperature of 2700 degrees F. If, therefore, the total return from blast-furnace gas is to be made comparable with that to be expected in high-temperature work, it becomes necessary to increase the percentage of total absorption through convection.

Until the past few years blast-furnace gas was regarded as more or less of a waste product. No particular effort was made to develop an efficient method of burning the gas and, as in the case of early waste heat work, any steam generated through its use was simply accepted as "something for nothing." As indicative of the efficiencies secured with blast-furnace gas, quotations from a paper presented before the American Iron and Steel Institute,* by Mr. Ambrose N. Diehl, are of interest:

> "The average efficiency of a blast furnace plant, using common burners and operating without the aid of technical supervision, is not over 50 per cent. and frequently much lower. . . .
>
> "Of a total of 60 Blast Furnaces in the Corporation under observance, the tests and information from the operators indicate a practice of not exceeding 55 per cent. The increase of 10 per cent. probably possible with improved conditions will show a yearly saving of one and one-half million dollars."

In line with other movements toward general conservation, steel-mill operators began to realize that any increase in the efficiency with which they could burn blast-furnace gas would result in a decrease in the consumption of a higher cost fuel in other portions of the plant.

Assuming a furnace of proper form and volume, the logical starting point in the development of any improved method of burning the fuel in question, was in the design of the gas burners. The designers and manufacturers of blast-furnace gas burners developed their product to a point where they were able to burn this fuel more efficiently than in the older practice. For com-

*Year Book of the American Iron and Steel Institute, 1915, pp. 344, 423.

bustion completed within the furnace the conditions were similar in all essential details to those under which our waste heat boilers had given eminently successful results. The gas temperatures entering the heating surface were no higher than in bee-hive coke-oven and in certain classes of heating furnace waste heat work. The gas weight, in common with waste heat practice, was higher than for coal firing; for, even with a minimum of excess air, the weight of products of combustion for blast-furnace gas is some 75 or 80 pounds per boiler horse-power developed, as against 45 or 50 pounds in the case of underfeed stokers. The furnace volume and the length of gas travel are the important factors. The furnace volume, measured in cubic feet per rated boiler horse-power, is some three times as great as the volume formerly believed to be ample in this kind of work. The furnace arrangement is, in general, designed to secure a maximum furnace temperature, rather than to expose any large proportion of the tube surface to the action of the radiant heat. These modern units operating at about their rated capacity are showing efficiencies of some 76 per cent. When operating at 200 per cent. of normal rating the efficiencies are approximately 73 per cent.

DISCUSSION

Mr. J. R. Mason:* What temperature do you consider about the minimum for using waste heat installations?

Dr. D. S. Jacobus: Some of our waste heat boilers are operating with an intake gas temperature of about 900 degrees F. The minimum temperature at which waste heat boilers may be used to advantage depends largely on the price of fuel at the particular point at which the boiler is located. In waste heat boilers we have installed in connection with oil stills, the temperature of the gases is about 1000 degrees F.

Mr. H. C. Cronemeyer:† I would like to ask a question regarding those boilers showing 73 to 76 per cent. efficiency. Is that over and above the steam used for the draft fan, or does it include that steam?

Dr. D. S. Jacobus: The figures are for the total efficiency and not the net efficiency obtained by deducting the steam for driving the induced draft fan. The heat in the steam for driving the fan can be returned to the feed-water in most cases, and where it is returned to the feed-water no heat is wasted except the comparatively small amount through radiation. In case the heat cannot be returned to the feed-water, an electric motor may be employed to advantage for driving the fan.

Mr. Lewis Vincent:‡ I would like to ask about the heat transmission factor.

Dr. D. S. Jacobus: This factor varies with the velocity of the gases. Ordinarily it runs from, say, 5 to 7 B.t.u. per square foot of heating surface per degree difference in the temperature between the gases and the surface.

*District Sales Manager, Wickes Boiler Co., Pittsburgh.
†Designer, Jones & Laughlin Steel Co., Woodlawn, Pa.
‡Consulting Gas Engineer, Pittsburgh.

Mr. Lewis Vincent: What are the ordinary velocities?

Dr. D. S. Jacobus: We ordinarily express the gas flow in terms of the weight of gases per square foot of flow area per hour, which for our waste heat boilers is above 2000 pounds. Generally this figure will be, say, 3500 pounds of gas per square foot of flow area per hour. A formula for working out the capacity of a waste heat boiler is given in "Steam, Its Generation and Use."* It required a vast amount of investigation to make sure of the constants in this formula.

Mr. John A. Hunter:† In your paper you stated that boilers were now being operated at ratings as high as 400 per cent. capacity. I would like to know the types of boilers that are being operated at these ratings; particularly, whether the Stirling boiler is being operated successfully at ratings of 200 per cent. and higher. I would also like to know the kind of boiler feed-water used in boilers at these high ratings.

Dr. D. S. Jacobus: The boilers I had in mind were Babcock & Wilcox boilers, although we have Stirling boilers operating at over 300 per cent. of their rated power. Where a boiler is operated at anything over 200 per cent. of its rating, one enters into a field of operation that requires expert attendance and careful attention to all details. Unless the feed-water is clean there surely will be tube losses and one should not endeavor to run at the higher ratings with poor feed-water.

Mr. M. F. McConnell:‡ Do you consider a feed-water which has been properly treated in a feed-water softening and purifying plant as suitable for boilers when operating at the high ratings which have been mentioned?

Dr. D. S. Jacobus: Some water, even if properly treated, could not be used to advantage for running at the highest ratings.

*Published by the Babcock & Wilcox Co.

†Steam and Sanitary Engineer, American Sheet and Tin Plate Co., Pittsburgh.

‡Superintendent, Mingo Works, Carnegie Steel Co., Mingo Junction, O.

The amount of foreign matter in the water might be such that to maintain the concentration of water in the boiler below a given figure would require so much water to be blown off from the boiler that it would materially reduce the efficiency. Where a water, after treatment, contains 120 grains of impurities per gallon, or more, there would be no economy in endeavoring to run at 400 per cent. of the rating, irrespective of how the water was treated, as the loss through blowing down the boiler would be excessive. This refers to the ordinary system of operation where the heat in the blow-off water is wasted. Should the heat be returned to the system, there would be little loss through blowing off; but, in general, in the case of such a feed-water, it would be advantageous to use an evaporating system for securing distilled water for the make-up.

MR. LINN HELANDER:* Are waste heat boilers used in connection with natural gas used for open-hearth furnaces?

DR. D. S. JACOBUS: We have some such installations fired by natural gas.

MR. G. C. EMMONS:† Do you think sufficient attention has been given to preventing air infiltration in the design and construction of waste heat boilers?

DR. D. S. JACOBUS: To prevent undue infiltration we apply a good stack paint when the boiler is in operation and the setting warm. When properly coated with the paint, and all joints sealed, the leakage is cut down to from 5 to 10 per cent.

MR. G. C. EMMONS: I wish you would show us how you do that. We have about 100 per cent. We have a ¼-inch boiler coating on practically new boilers.

DR. D. S. JACOBUS: We will gladly co-operate with you in getting at the source of the difficulty. One thing that should

*General Engineering Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

†Efficiency Engineer, Republic Iron & Steel Co., Youngstown, O.

be borne in mind in discussing the question of air leakage, is that it is very difficult to determine the amount accurately. The only way to determine the leakage is by making gas analyses, and it is difficult to secure an average sample of the gases. If there is 100 per cent. leakage of air into the settings of your boilers there is something radically wrong.

Mr. G. C. Emmons: Would you now advocate the use of economizers as a general proposition?

Dr. D. S. Jacobus: Each case must be considered by itself. In waste heat boilers used in connection with cement kilns, or any other service where the conditions are reasonably uniform, economizers may be used to a greater advantage than where the weight of the gases and the temperature vary to a great extent. We now know where we stand in preventing corrosion of wrought-steel economizers and this broadens the field of the use of economizer elements in waste heat boilers and will, no doubt, have an important bearing in waste heat work.

Mr. H. C. Cronemeyer: Relative to infiltration of air, has an attempt ever been made to use concrete boiler settings lined with fire-brick?

Dr. D. S. Jacobus: We installed such a setting in connection with a direct fired boiler used for experimental purposes, and secured good results; but, so far, we have never used concrete settings in any commercial installation.

Mr. H. C. Cronemeyer: You showed an illustration showing boilers connected to several furnaces and spoke of simple dampers to cut out any one of the units. Have you tried a more elaborate style of damper? Those shown would be almost impossible to manipulate during the period of operation.

Dr. D. S. Jacobus: We have used simple dampers as well as water cooled dampers.

Mr. H. C. Cronemeyer: Do these have finished surfaces? If they do not, the leakage past the dampers would admit a great deal of cold air and reduce the efficiency.

DR. D. S. JACOBUS: The dampers rest directly against the brickwork and there would be little or no gain through finishing the surfaces. The amount of leakage when properly constructed is relatively small.

MR. LEWIS VINCENT: We have recently installed a Wickes vertical water-tube boiler set up with a 4½-inch inside lining of brick and a 4-inch outside layer of cement and sil-o-cel powder paste, which approximates to some extent the concrete shell suggested. We used to put up these boilers with 4½-inch fire-brick lining and outside of that a steel case with a 4-inch space between the steel case and the brick filled with loose sil-o-cel powder. We found some trouble with the steel shell and have substituted the plaster around the outside as better construction, the idea being to allow constant inspection of the exterior surface of the boiler setting. Frequent washing of this surface with an insulating paint or solution will fill up any cracks that may develop.

With the powder insulation and steel shell, we have found it impossible to inspect the condition of the setting, and hard to rectify any faults that might develop. While, no doubt, the steel shell prevents the infiltration of air, the loose insulating powder settles in time under conditions of loading and heat; and, cracks eventually developing in the brick lining, this powder is sucked into the setting by the vacuum carried inside. In consequence, hot spots frequently form on the plate lining and troubie develops.

The boiler mentioned above is just going into operation at the plant of the Philadelphia Suburban Gas & Electric Company, Chester, Pa., and I shall be glad to advise any one interested as to the results obtained in operation.

MR. GRANT D. BRADSHAW:* Referring to the temperature of gases, you spoke of the necessity of using the waste heat type of construction where temperatures were around 2000 degrees, and previous to that you spoke of combustion temperatures with coal fires as being around 2700 degrees. We have obtained some very good results with the standard type of Babcock & Wilcox construction, where the combustion temperatures were maintained

*President, Andrews-Bradshaw Co., Pittsburgh.

around 2300 degrees. Of course, with that temperature, the effect of radiation would be considerably greater than at 2000 degrees. Under those conditions, however, we have been able with a three-pass Babcock & Wilcox boiler, to maintain an efficiency of 78 per cent. continuously over a period of a month. Of course, these temperatures are somewhat higher than Dr. Jacobus mentions, but it is a condition that is perfectly possible.

Dr. D. S. Jacobus: What kind of fuel produced the furnace temperature of 2300 degrees?

Mr. Grant D. Bradshaw: Uncleaned blast-furnace gas, at about 350 degrees initial temperature, and between 90 and 95 B.t.u. per cubic foot.

Dr. D. S. Jacobus: You must have obtained good furnace and combustion conditions to secure a temperature of 2300 degrees and the correspondingly high efficiency.

Mr. Grant D. Bradshaw: With a standardized pyrometer, we have run an eight-hour test at about 2400 degrees. That was a low-moisture gas. The moisture content of the gas itself has a good deal to do with the temperature, but under commercial conditions 2300 degrees is entirely possible.

Dr. D. S. Jacobus: What do you estimate the radiation loss to be in computing the efficiency?

Mr. Grant D. Bradshaw: Five per cent. How does that compare with your experience with Babcock & Wilcox boilers?

Dr. D. S. Jacobus: Our tests of direct fired boilers gave lower figures than five per cent. for the radiation loss. In your test, how high were the boilers set and how large was the furnace?

Mr. Grant D. Bradshaw: The furnace volume was somewhat larger than the old-fashioned practice about which you spoke. I do not know exactly what it was, but it was below two cubic feet per horse-power.

DR. D. S. JACOBUS: To secure as high an efficiency as you obtained, all of the gas must have been burned within the furnace with little or no secondary or delayed combustion between the boiler tubes.

MR. GRANT D. BRADSHAW: Practically all the gas in the furnace. The combustion is complete.

MR. F. E. LEAHY:* There are installed at the Duquesne Steel Works of the Carnegie Steel Company, five 1290 horsepower Babcock & Wilcox boilers of the waste heat type. These have been in operation for approximately a year and a half.

The efficiencies as quoted by Dr. Jacobus—about the same as obtained here—are not corrected for the steam used by the auxiliaries for the reason that the boiler auxiliaries are turbine driven and the exhaust steam from these is returned to the heater and recovered. This would require a very small correction for radiation loss as affecting efficiencies, but the capacity should be reduced by the amount of steam required to operate the boiler auxiliaries.

The fuel used was washed blast-furnace gas. The flame temperature was measured six feet from the burner by means of a Leeds & Northrup optical pyrometer which was checked by a Le Chatelier pyrometer, the thermo-couples of which were encased in a water-cooled protecting tube. The temperature obtained in the fire-box varied from 1800 to 1900 degrees F. Combustion was practically completed before the gas entered the tubes in the first pass. The flame temperature in the combustion chamber appears low for the excellent combustion obtained, but is accounted for by the fact that the roof of the combustion chamber located under the boiler is formed by encircling tile placed on the bottom row of tubes. This makes a water-cooled roof so that the flame temperature obtained is lower than that which would have been expected where the combustion is completed free from radiation or heat absorption by any of the boiler surfaces.

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The capacity obtained from the boilers varied from 150 to over 200 per cent. of the normal rating for a period of 24 hours. The burner was found capable of handling sufficient gas—at a pressure, measured in the burner manifold, of from 0.5 inch to 1.5 inches of water—to develop from the rating to slightly above 200 per cent. of the rating.

Difficulty was experienced, at first, in preventing air infiltration, which was discovered to be greatest at the front and rear headers, especially at the nipples connecting the headers. This was eliminated by placing lap-jointed plates over the front and back of the nipples and pouring in a mixture of cement. The baffles were strengthened and, after this was done, no further difficulty was experienced with air infiltration. At no time were the side walls found to be serious factors in causing air infiltration.

Mr. Grant D. Bradshaw: I would like to ask Mr. Leahy what type of joint was used at the top of the boilers between the side walls and the roof alongside the longitudinal drum to prevent air infiltration?

Mr. F. E. Leahy: We have a loose joint there to take up the expansion and contraction. It is packed with asbestos and kept as tight as possible.

POWDERED COAL

By John E. Muhlfeld*

OUTLINE

GENERAL

There is probably no other engineering subject on which has been presented so much data, based on speculative and deductive reasoning, as that of powdered coal; and the time has now arrived when such information—including much misinformation—should be supplanted by conclusions based on specific knowledge gained from the results of actual practice.

The facts that about one-half of the earth's known coal resources—or over three and one-half trillion tons—lie in the United States, and that this country annually mines about forty per cent. of the world's coal production, give evidence that we will depend largely upon its use for power, heat, and light for many years to come. Therefore, any method that can be devised to utilize this fuel of the present and the future in a way that will better provide for the necessities, health, and comfort of human life—and at the same time in a more effective and economical manner—is deserving of every consideration, particularly now that its average quality is decreasing and the cost of its production and distribution is increasing annually.

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Ask any man behind the furnace, whether it be for steam generation or metallurgical or chemical heating purposes, whether he prefers a fuel of equivalent heat value that can be burned in suspension—that is, gas or oil—or one that can be burned on grates or in retorts—that is, coal, coke, lignite, or wood—and, if he has had experience with both, he will invariably be in favor of the former. For this opinion there are many good, practical reasons which, regardless of the important factor of conservation, fully justify the use of solid carbonaceous fuel in powdered for.

However, so much has been presented on the subject of powdered coal in the way of glittering generality, unsupported by authenticated records, that self-protection compels the statement that the burning of solid fuels in suspension is not yet the solution of every combustion difficulty. My personal experience during the past 25 years with the use of gaseous, liquid, colloidal, and powdered and lumpy solid fuels for stationary, locomotive, and marine boiler and heating furnaces leads me to present, at this time, the following conclusions:

1. Decision regarding the substitution of powdered anthracite, bituminous coal, lignite, or peat for any other fuel should be reserved until a careful, unbiased, expert analysis has been made of the comparative costs. This analysis should include installation, interest, depreciation, taxes, insurance, operating and up-keep expenses, from the source of fuel supply to the stack. An example of such an analysis is presented in the Appendix to this paper.

2. No system of powdered fuel drying, milling, storage, distribution, feeding, or burning should be considered for a permanent installation unless it provides for the prime necessities of proper fuel preparation and handling, correct firing and furnace design, and satisfactory operation; and unless it has demonstrated, in actual operation, its adaptability, practicability, safety, efficiency, and economy with the fuel to be used, for the kind of service required.

CONDITIONS JUSTIFYING THE USE OF POWDERED COAL

In general, the factors justifying the serious consideration of the use of powdered coal may be stated as follows:

1. Daily consumption of 80 tons, or more, of average commercial coal, or other solid fuel equivalent, from one preparation plant.
2. Necessity for greater output from existing equipment.
3. Available supply of cheap low-grade fuel.
4. Special operating requirements, such as irregular and peak loads; exacting character (neutral, oxidizing, or reducing), length, or direction of flame; and excessive banking and stand-by periods.
5. Advisability of reducing the human element factor, particularly as relating to arduous non-productive labor.
6. Desirability of minimizing fuel and labor, both of which are expensive.
7. Expensive ash-handling, and boiler and furnace up-keep.
8. Necessity for reduction of smoke, soot, sparks, and cinders.
9. Available gaseous, liquid, or solid fuels for use in the same furnaces in combination or independently.

The Appendix to this paper sets forth the relative values of powdered and stoker fired coal, but it is also of interest to note the comparative purchasing power of one cent with various fuels, based on their heat values at the furnace. This comparison is presented below:

Powdered Bituminous Coal

B.t.u. per pound	12,000
B.t.u. per ton	24,000,000
Cost per ton (including handling, pulverizing, and transmission to furnace	$ 5.50
B.t.u. for one cent	43,636

Natural Gas

B.t.u. per cubic foot		960
B.t.u. per 1000 cubic feet		960,000
Cost per 1000 cubic feet		$ 0.25
B.t.u. for one cent		38,400

Producer Gas

B.t.u. per cubic foot		130
Producer efficiency, per cent		78
Cost of coal	$4.95	
Cost of labor	0.65	
Cost of power	0.40	$ 6.00
B.t.u. available in gas from one ton of coal (12,000 B.t.u. per lb. of coal		18,720,000
B.t.u. for one cent		31,200

Fuel Oil

B.t.u. per pound		19,000
Pounds per gallon		7.3
B.t.u. per gallon		138,700
Cost per gallon		$ 0.09
B.t.u. for one cent		15,411

In view of the foregoing, the equivalent fuel cost values are as follows:

Powdered coal at $15.56 per ton equals oil at 9 cents per gallon.

Powdered coal at $7.65 per ton equals coal for producer gas at $4.95 per ton.

Powdered coal at $6.25 per ton equals natural gas at 25 cents per 1000 cubic feet.

Coal for producer gas at $10 per ton equals oil at 9 cents per gallon.

Coal for producer gas at $3.83 per ton equals natural gas at 25 cents per 1000 cubic feet.

Practical operating results at a power-plant using both powdered coal and fuel oil have proved that the increased efficiency from powdered coal—probably due to the radiant effect of the ash in suspension in a boiler furnace—is sufficient to offset the actual increased cost of pulverizing, handling, and firing of solid

fuel as compared with the cost of firing fuel oil. Thus the comparative cost can be considered on a B.t.u. basis, irrespective of the amount and character of the ash, which, in the ordinary practice of firing, makes it difficult to maintain combustion, and which decreases so largely the overall efficiency of the combined furnace and boiler.

Take a specific instance, with run-of-mine bituminous coal of about 12,500 B.t.u. content per pound, costing $3.75 per ton, and fuel oil of about 19,000 B.t.u. content per pound, costing 90 cents per barrel, both delivered alongside the power-plant. The heat value purchased per dollar would be 6,666,666 B.t.u. for coal, and 6,561,333 B.t.u. for fuel oil, and the net operating result, in terms of cost for steam produced, shows a slight difference in favor of the powdered coal.

COST OF INSTALLATION

Until the World War, the United States had been particularly fortunate by reason of its readily accessible deposits of thick-vein, high-grade anthracite and bituminous coal. This coal could be mined with relatively low cost for labor and could be distributed to consumers at the lowest transportation cost in the world. However, with the annual depletion of the thick-vein coal; the higher cost for propping, haulage, pumping, lighting, ventilation, and powder used in mining; the advancing labor wage scale; and the necessarily increased freight rate, the item of fuel cost has increased from two to three times its former value and has become a proportionately increased percentage in the operating costs of railroads, public utilities, and industries. During the same period that fuel costs have increased so enormously, interest rates have increased only from an average of 5 to 7, or about 40 per cent.

Therefore, an installation and annual fixed charge cost, that would have been prohibitive a few years ago, for converting equipment to the use of powdered coal, is, through the large operating savings now possible, made not only permissible but in many cases a necessity, if protection is to be afforded to the transportation and industrial corporations that are at present and will be in the future seriously affected by high fuel costs.

Reference to items 8 and 9 in the Appendix to this paper, will give a general idea as to the relation between the extra investment cost to install equipment for the use of powdered coal, and the net annual savings as produced therefrom.

COST OF HANDLING AND PREPARING COAL

The plant required, the investment and fixed charges, and the expense of preparing a ton of coal, preparatory to burning it in powdered form, have been the principal factors in retarding its more general use for steam generation and heating furnace purposes.

From the Appendix, the following items have been taken:

No.	*Item*	*Powdered coal*	*Stoker*
71.	Total cost of preparation, per ton prepared......	$0.3325	$0.009
83.	Total cost of handling in distributing system per ton	0.0440	0.0494
99.	Total cost of boiler firing, per ton fired...........	0.5376	0.7933
100.	Total cost of preparing, distributing, and firing coal, per net ton........	0.9141	0.8517

The foregoing figures include the cost for fixed charges, power, maintenance, lubricants and labor required for handling a ton of coal from alongside the plant to the stack and the disposal of its ash. When all these factors are included, the difference between the cost per ton for preparing and putting either—the powdered and stoker fired coal—through the furnace, is not as great as is generally supposed. Furthermore, considerable reduction can be made in the present cost and complexity of the preparing plant and distributing equipment for powdered fuel. Much of that now sold and used is most extravagant in the cost for maintenance as well as in the use of power for its operation.

Then, too, the determination for each kind of fuel used, as to the proper dryness and fineness required for the best overall results, is an important preparation cost factor that has received too little careful analysis. Very frequently it has been found that extremely fine grinding is unnecessary, and that little or no mechanical drying is required for satisfactory results. This depends,

of course, upon the character of the fuel and of the conveying, feeding, and burning equipment used. For example, I know of a steel plant near Pittsburgh where the coal is conveyed direct to an air separation type of pulverizer and, without mechanical drying, is very successfully used in re-heating and stationary boiler furnaces.

THERMAL EFFICIENCY

The value of "combined efficiency," which is generally used as a basis for comparing the performance of different methods of firing furnaces, is somewhat questionable unless all conditions are known and understood and accompanied by the "heat balance." For example, a 98 per cent. furnace efficiency in combination with a tea-kettle, which due to design and conditions could not absorb the heat offered to it, would produce a very poor "combined efficiency" as compared with an 85 per cent. furnace efficiency in combination with a first-class boiler.

There is no question but that, with certain powdered coal equipment and boiler furnace combinations, from 98 to 99 per cent. of the combustible fired is reduced to CO_2. To secure the absorption of the heat so generated by the boiler, however, is something outside the province of the combustion engineer. With various types of steam generators there has been no difficulty in keeping from one to five boilers operating continuously for from 24 to 96 hours, at from 125 to 200 per cent. ratings; combined efficiencies of from 78 to 85 per cent., gross; and from 75 to 81 per cent., net; this difference between the gross and net being due to a reduction on account of the evaporation from boilers necessary to provide power for crushing, handling, drying, pulverizing, and firing the powdered coal.

COMBUSTION

It is a relatively easy matter to prepare and burn powdered fuel, but the erroneous idea that an ordinary furnace, equipped with a common blast or induction inlet into which fuel can be fed as a predetermined admixture of air and fuel or by a piece of gas pipe fitted with a feed screw, will produce a proper degree of capacity, efficiency and economy, has resulted in many otherwise avoidable failures and delays.

The justification for burning solid fuel in powdered form is that when reduced to the proper dryness and fineness for its character, and handled in a manner to prevent the re-absorption of any considerable moisture, it will produce a quick chemical reaction or combustion when passed, in suspension, through a relatively high-temperature furnace zone containing free oxygen; and will not be affected by any lack of temperature transfer through the fuel particles, or by intervening non-combustible between the combustible and the free oxygen.

Therefore, to burn powdered coal effectively, all necessary air must be supplied to the combustion zone, progressively, by induction. This is to enable the expansive action of the gases in that zone, resulting from the great affinity between the carbon or carbonaceous gases at high temperatures, to set up a circulatory motion and enable each particle of combustible to come into intimate contact with the requisite oxygen for complete chemical reaction, the gases displacing surplus air and more or less automatically regulating the supply of oxygen. When air is forced into the combustion zone under pressure, it must necessarily be in predetermined quantities in relation to the B.t.u. in the fuel supply (if complete, efficient combustion is to take place) and such regulation is practically impossible.

The process of chemical reaction having been completed, such combination of air control and flame travel must then be provided as will insure proper control of the temperature as well as the conversion of the highly radiant liquid non-combustible to low-temperature dry particles. This is effected by passing through a neutral air zone, for absorption of heat and to prevent the reduction of ferric sulphid to ferrous sulphid. This latter reduction is the direct cause for the formation of honeycomb as well as troublesome molten slag.

Frequent reference is made to the high CO_2 obtainable with powdered fuel firing, whereas it is a well-known and accepted fact that the percentage of CO_2 in the gases is only indirectly a measure of furnace efficiency. Furthermore, when the average CO_2 at the stack goes beyond 15 to 16 per cent., dependent upon the character of the fuel, trouble from molten slag commences.

Powdered fuel undoubtedly offers the best means of getting high furnace efficiency from low-grade fuels. Those of high volatile content, when grate or retort fired at any but low rates, always lose a large proportion of the gaseous combustible to the stack, unconsumed. This is due to the considerable volume liberated, and the impossibility of proper mixing over the fire—such as is obtainable with powdered fuel. Likewise, fuels of low volatile content, when burned in powdered form, can be made to produce excellent results through regenerative action, with proper furnace design.

Again, with all low-grade coals and lignites, it is practically impossible to burn them in a lumpy form and maintain combustion conditions over any considerable period of time; or to maintain a fire-bed of equal thickness without clinker or air holes. As fuel burned on grates or in retorts is a combination of a gas-producer and a gas-burning chamber, much of the heat of the high-temperature non-combustible is lost by the heat-absorbing surfaces, due to its being carried away into the ash-pit, etc.

FURNACE AND FLUE-GAS TEMPERATURES

Temperature, as the result of combustion, is affected by excess oxygen, excess nitrogen, and time. While these three elements are all factors which enter into the control of furnace temperatures, none of them has any material effect on any particular loss of the useful heat available for work, when regulated to control temperature.

The refractory which is essential for primary combustion and regenerative action in a furnace for burning powdered fuel, is the limiting factor as regards the obtainable and permissible temperatures. In ordinary heating furnaces, where the exposed heat-absorbing surfaces are relatively small, there is no difficulty in producing and regulating temperatures of from 3100 to 3200 degrees F. In locomotive-type boiler fire-boxes, where a large area of heat-absorbing surface is exposed to combustion, temperatures of from 2600 to 2800 degrees F. are easily regulated and maintained.

However, to control these temperatures properly, and produce efficient results with powdered fuel, requires not only proper

furnace design and equipment, but also certain arrangements for fuel feed, burner, primary and secondary air supply, and draft. With these, it is a relatively easy matter to maintain a uniform temperature of the desired degree for any period of service, or to increase or decrease it within the working range, at will.

With respect to flue-gas temperatures, these are generally no higher than for other fuels and methods of burning. This is due largely to the fact that powdered fuel requires less excess air for complete combustion. Therefore, the products of combustion have a higher heat value per cubic foot of furnace volume, with the result that less gas must be conveyed to and through the heat absorbing surfaces to produce a given heat result. This permits of a reduction in the velocity of the gases from the furnace to the stack, and the absorption of a greater amount of heat from these gases.

Uuder certain conditions, where flue-gas temperatures from powdered fuel may be higher than from coal burned on grates or in retorts, due consideration should be given to the fact that these gases carry in suspension impalpable particles of ash that have a higher specific heat value than the gas itself. These ash particles act as an effective medium for the transfer of heat. They increase the B.t.u. value of each cubic foot of gas passing through the furnace or steam generator to the stack; whereas, in stoker practice they pass from the fire chamber to the ash-pit, where the heat is entirely lost.

RADIANT HEAT

When solid fuels are burned on grates or in retorts, the radiant heat is at a minimum and the convection heat is at a maximum; whereas, when the same fuel is burned in powdered form, this condition is reversed.

Efficiency of heat transfer through boiler-plates and tubes is materially greater with a radiant heat than with a convection heat, this increase being from 20 to 25 per cent. as applying to those portions of the heating surfaces directly affected by the incandescent, non-combustible particles which have passed through the minimum distance.

In a powdered fuel flame, the impalpable ash offers a medium by which the heat of combustion is converted into radiant energy, whereas, in a stoker installation the mass of the combustion gases, although having the necessary temperature, has no medium other than the refractory material in the walls of the furnace, through which to become radiant.

Heat radiates in straight lines, and, from observations taken for furnaces burning powdered coal, intense white flame occurs not only below the first row of tubes but well into the tube bank. From this it is apparent that the radiant effect of the incandescent, impalpable ash particles is obtained by fully one-half of the total heat-absorbent surface of the first pass of the boiler, as compared with the radiant heat effect of a much lesser degree which is obtained by only the lower half of the first row of tubes exposed to the fire bed of a stoker installation. Hence it may be concluded that with the results of combustion identical, as regards furnace and exit gas analyses and temperatures, the efficiency of the boiler fired with powdered fuel will be substantially greater, due to the more effective transfer of radiant heat.

NON-COMBUSTIBLE MATTER

Exclusive of moisture, commercial steam coals contain from 5 to 25 per cent. of impurities, which means that out of every ton of 2000 pounds, from 100 to 500 pounds has practically no heat value and is further detrimental.

For all practical purposes, the eight principal impurities that occur in coal may be generalized as follows:

Material	*Percentage of total impurities*
Silica	25 to 55
Alumina	15 to 35
Iron	10 to 30
Sulphur	trace to 5
Calcium	trace to 5
Potassium	trace to 3
Sodium	trace to 2
Magnesium	trace to 2

These impurities come from three sources—vegetable material; clay, sand, or shale; and extraneous substances—and combine to form a mechanical mixture of silicates, oxids and sulphates. With the exception of sulphur, which is an undesirable element and occurs as iron pyrites or calcium sulphate, all are non-combustible. In general, the silica, alumina, and magnesium content will tend to decrease, while the iron, calcium, potassium, and sodium content will tend to increase the fusibility of the impurities in the coal.

The clinkering and honeycombing of the impurities in coal is one of the most destructive results of combustion where fuel is burned on metal surfaces, and its formation may be either chemical or by adhesion or fusion of particles of ash and combustible into slag. Roughly, each 1 per cent. of impurities causes a decrease of from 0.5 to 1 per cent. in combustion efficiency, and from 1 to 1.5 per cent. in boiler capacity. As practically all the oxygen disappears at a few inches above the grate, this applies particularly where agitation of the fuel bed mechanically mixes the impurities with the combustible and converts the former into the more fusible ferrous silicates, with resultant clinkering and honeycombing.

The tendency of coal to clinker varies almost directly with the content of iron pyrites and inversely with the ash content. When the ash is low in relation to the sulphur content, clinkering is usually extremely bad unless a cooling process, or a counteracting agent such as limestone, is applied to the grates to prevent fusing of the clinker thereto. The pyrites, which is the principal slag-forming material in coal, when reduced to ferrous sulphid passes into a molten state at about 2150 degrees F. and in combination with the ash forms layers of solid clinker on top of the grates, and stops the passage of the air. The result is that the grates become overheated and cause the clinker to melt and flow through the grate openings. This results not only in clogging and warping the grates, but also in their corrosion and destruction, due to the sulphur combining with the overheated metal.

While the sulphur itself has little to do with the fusibility of the ash, the iron, combined with a part of the sulphur, does. In general, the greater the percentage of iron the more fusible the

slag. Furthermore, fused ferrous sulphid fluxes aluminum silicate and also causes clinker.

With the grates clinkered, there is insufficient air for complete combustion, with the result that ferrous oxid is formed and unites with the silica to form honeycomb which becomes very fusible at temperatures over 2400 degrees F., and will tend to adhere to those portions of the boiler metal and furnace refractories where the temperature is highest.

Thus we find that—due, primarily, to lack of air supply through the metal work on which the fuel bed is placed—we have the cause of both clinker and honeycomb in the production of ferrous sulphid and ferrous oxid, respectively, which, in turn, have a most destructive effect not only on the metal work which is responsible for the restricted air supply, but on the refractory surfaces as well.

When coal is properly prepared and burned in powdered form, the usual difficulties resulting from clinker are eliminated as there are no grates or retorts on which it can accumulate, and it cannot interfere with the air supply requisite for combustion. However, with coal that contains certain intrinsic combinations of ferrous silicates which fuse at relatively low temperatures (2000 to 2300 degrees F.) honeycomb formation will result unless the proper fuel, air, and draft regulations obtain to convert the ferrous sulphid into ferric oxid which is the result of complete combustion and requires 50 per cent. more oxygen or dry air to produce than ferrous oxid. For this process an oxidizing atmosphere must at all times obtain in the combustion chamber in order to prevent the reduction of ferric sulphid to ferrous sulphid and, as the burning of fuel in suspension is not dependent upon air supply through openings that are liable to become clogged, this can easily be provided.

One important factor that is frequently overlooked with powdered coal installations is the necessity for equipping all furnaces and boilers with effective means for blowing out the fine ash that frequently accumulates on top of the various surfaces. Unless provision is made for this important detail, much otherwise avoidable difficulty is bound to occur with fuel running high in impurities.

REFRACTORIES

Where powdered fuel is used, too much importance cannot be placed on the kind of refractory and the arrangement of the heat-absorbing and radiating walls of furnaces for the purpose of flame and radiant heat propagation, in order to prevent the brick from becoming porous, fluxing away, or scouring out by the corrosive ash or erosive flame.

As to the refractory itself—which must resist the destructive agencies of temperature, slag, load, abrasion, corrosion, and eutectic action—this should preferably be a pressed rather than a hand-molded product, of a dense medium-ground quality that will stand up under a temperature of 3100 degrees F. It should be properly made to insure against cracking, warping, spalling, crushing, and slag penetration. Such brick when properly laid up with the least possible fire-clay or cement, will, under the conditions obtainable with the better class of powdered fuel equipment, last almost indefinitely with minor periodical renewals.

Another important point, too frequently overlooked, is to equip and operate such furnaces so that the ash and clinker can be cleaned out of the furnace, regularly and thoroughly.

Last, but not least, no powdered fuel furnace should be forced to the point where the temperature of combustion cannot all be quickly absorbed or removed from the combustion chamber, as would occur from inadequate or obstructed gas passages to the atmosphere. Much refractory has been ruined by this deficiency and the blame placed on the powdered fuel, which was in no way at fault.

UP-KEEP

The cost for the up-keep of a powdered coal installation is one that repeatedly comes up when a comparison is made with stoker firing.

From the Appendix the following items have been taken, and, of course, are included in the figures already given under the cost of handling and preparing coal:

No.	Item	Powdered coal	Stoker
68.	Cost of maintenance of preparation plant, per ton prepared	$0.0400	$0.00
80.	Cost of maintenance of distributing system, per ton handled	0.0025	0.04
95.	Cost of maintenance of boiler equipment, per ton fired	0.0200	0.14
97.	Cost of furnace repairs, per ton fired	0.0400	0.03
	Total cost of up-keep	$0.1025	$0.21

Anyone who has had experience with grate and retort stokers will know of the large number of repair parts that must be carried in stock, of the maintenance charges for renewal of castings and forgings inside of the combustion zone, and of the damage to the refractories in side and bridge walls at the line of the fuel bed, on account of forced blast, ash and clinker—all of which, with the consequent delays in service, are eliminated with powdered coal.

HUMAN ELEMENT

At no time more than during the past three years have we learned the result of individual effort ineffectively, inadequately and unintelligently applied. On the railroads, and in other industries using heat for steam generation and for industrial purposes, the uncontrollable human factor has had its most serious effect on the domestic and commercial fuel supply of the world. This was due largely to the existing methods of firing, combustion, and ash-handling, requiring the use of large labor forces at arduous and non-productive work.

To show what powdered fuel can do to relieve this situation, it is only necessary to cite an instance near your city where the conversion of two continuous, billet-heating furnaces from hand fired to powdered coal, reduced the total number of workmen, per 24-hour period, from 36 to 7; and reduced the fuel consumption from about 450 to 160 pounds of coal per ton of metal heated, with a production of about 150 tons per furnace, per turn. While this may be a striking example, it is indicative of what can be accomplished in labor and fuel saving through

the use of automatic mechanical methods for the production of heat from solid fuels.

CLEANLINESS

The discomfort and economic loss due to smoke, sparks, and ashes justify due consideration of any method of relief. This is especially true when the improvements will justify their cost by increasing capacity, reducing labor, and minimizing the wastes and nuisances caused by incomplete combustion.

Sufficient evidence of the effectiveness of powdered fuel is now available in various towns and cities where the results from this method, as compared with stoker and hand firing of coal on grates, and with fuel oil, can be demonstrated.

SAFETY

During the early use of powdered fuel a number of fires and explosions occurred, due invariably to the use of hazardous methods or to failure to observe the proper instructions.

As has been the case with all mediums for the production or concentration of greater heat and power, there is in the use of powdered fuel a certain element of danger which does not exist with the more ineffective coarse, solid fuels; but, with existing equipment and regulations for the use of powdered fuel, it is a comparatively easy matter to avoid trouble from spontaneous combustion, fires, or explosions.

APPENDIX

COMPARISON OF TOTAL OPERATING EXPENSE, POWDERED COAL VS. STOKER FIRING, FOR 22,000 HORSE-POWER NOMINAL RATING, BOILER PLANT IN COMBINATION WITH 45,000-KILOWATT CENTRAL POWER STATION

Number	*Item*	*Powdered coal*	*Stoker*
	Summary		
1.	Total cost of coal per net ton, as fired (item 12 + 100)........................	\$3.7141	\$3.6517
2.	Boiler horse-power hours developed per net ton of coal (2000 ÷ item 41)	639	583

Number	Item	*Powdered coal*	*Stoker*
3.	Boiler horse-power hours developed per dollar expended for fuel and labor	172	160
4.	Cost of firing per 100 boiler horse-power hours developed	58c.	61.5c.
5.	Cost of firing per boiler horse-power year (3000 hours)	$17.40	$18.75
6.	Cost of firing per kilowatt-hour produced	0.00286	0.00307
7.	Total cost of producing steam per year	$1,710,847	$1,888,126
8.	Net savings per year after deducting interest, depreciation, taxes, insurance and all operating and maintenance expenses	$ 177,279	....
9.	Extra investment required in order to effect saving in item 8	$ 142,000	....
	General data		
10.	Kind of electric current available	d. c. or a. c.	d. c. or a. c.
11.	Cost of electric current per kilowatt-hour	0.75c.	0.75c.
12.	Cost of coal, per net ton, alongside	$2.80	$2.80
13.	Water, per kilowatt-hour, including auxiliaries	17 pounds	17 pounds
14.	Hourly rate and hours per day for firemen (24 hours at 45c.)	(3) $ 32.40	(5) $ 54.00
15.	Hourly rate and hours per day for assistant firemen (24 hours at 43.5c.)	(3) $ 31.22	(5) $ 52.20
16.	Hourly rate and hours per day for ash handlers (10 hours at 42c.)	(2) $ 8.40	(6) $ 60.48
17.	Hourly rate and hours per day for millers (20 hours at 54c.)	(1) $ 10.80	....
18.	Hourly rate and hours per day for millers' helpers (20 hours at 43.5c.)	(3) $ 26.10	....
19.	Hourly rate and hours per day for conveyor attendant (20 hours at 45c.)	(1) $ 9.00	(1) $ 10.80
20.	Hourly rate and hours per day for inspector (24 hours at 54c.)	(1) $ 12.96	(2) $ 25.92
21.	Total labor per 24-hour day	$130.88	$203.40

Number	Item	Powdered coal	Stoker
	Coal analysis, as fired		
22.	Run-of-mine	bituminous	bituminous
23.	Moisture	0.8	0.8
24.	Volatile matter	33.58	33.58
25.	Fixed carbon	56.02	56.02
26.	Ash	9.6	9.6
27.	Sulphur	less than 1%	less than 1%
28.	B.t.u.	13,380	13,380
29.	Number and kind of boilers	(14) B.&W.	(14) B.&W.
30.	Rated horse-power of each	1600	1600
31.	Total horse-power capacity of plant	22,400	22,400
32.	Hours per day operated	24	24
33.	Hours per day banked	6	6
34.	Days per year operated	365	365
35.	Average rating during operation	150	150
36.	Horse-power hours operated per year	294,336,000	294,336,000
37.	Average B.t.u. in fuel	13,380	13,380
38.	Average combined efficiency	80	73
39.	B.t.u. utilized in boiler and super-heater	10,704	9,767.4
40.	Pounds water evaporated from and at 212 degrees per pound of coal	11.03	10.065
41.	Pounds coal per boiler horse-power hour	3.13	3.43
42.	Pounds coal per hour during banked period	......	11,200
43.	Pounds coal per day while operating	2,524,032	2,765,952
44.	Pounds coal per day while banked 0.5 pound per horse-power capacity per hour	....	67,200
45.	Pounds coal per day, total for plant	2,524,032	2,833,152
46.	Tons coal per year, total	460,635.8	517,051.2
47.	Tons coal per hour in preparation plant (20 hours per day)	66	....
	Installation costs		
48.	Cost of preparation plant building, including foundation and bins	$ 80,000	....
49.	Cost of preparation plant machinery and equipment	220,000	$25,000
50.	Cost of distributing system machinery	75,000	see item 58
51.	Cost of distributing system supports	see item 58	....

Number	*Item*	*Powdered coal*	*Stoker*
52.	Cost of boiler bins and supports	see item 58	....
53.	Cost of boiler firing machinery and equipment	240,000	487,000
54.	Cost of boiler furnaces	84,000	see item 53
55.	Cost of boiler room changes, when necessary	....	....
56.	Cost of ash handling equipment	20,000	65,000
57.	Cost of soot blower system	10,000	10,000
58.	Cost of boiler, installed	$1,456,000	$1,456,000
59.	Total	$2,185,000	$2,043,000
	Operating expense—Preparation plant		
60.	Total investment (item 48 + 49)	$300,000	$25,000
61.	Interest at 7% on item 60	21,000	1,750
62.	Depreciation at 5% on item 48	4,000	....
63.	Depreciation at 10% on item 49	22,000	2,500
64.	Insurance and taxes at 2% on item 60	6,000	500
65.	Total fixed charges on item 60	53,000	4,750
66	Total fixed charges on item 60, per ton prepared (item 65 ÷ item 46)	0.115	0.009
67.	Cost of electric power per ton prepared	0.0975	....
68.	Cost of maintenance per ton prepared	0.0400	....
69.	Cost of lubricants per ton prepared, plus coal for drying	0.05	....
70.	Cost of labor per ton prepared	0.03	....
71.	Total cost of preparation, per ton prepared	0.3325	0.009
	Operating expense—Distributing system		
72.	Total investment (item 50 + 51)	$75,000	see item 58
73.	Interest at 7% on item 72	5,250	....
74.	Depreciation at 5% on item 51	....	....
75.	Depreciation at 10% on item 50	7,500	....
76.	Insurance and taxes at 2% on item 72	1,500	....
77.	Total fixed charges on item 72	14,250	....
78.	Total fixed charges on item 72 per ton handled (item 77 ÷ item 46)	0.031	....
79.	Cost of electric power per ton handled	0.0015	0.0008
80.	Cost of maintenance per ton handled	0.0025	0.04
81.	Cost of lubricants per ton handled	0.002	0.001

Number	*Item*	*Powdered coal*	*Stoker*
82.	Cost of labor per ton handled	0.007	0.0076
83.	Total cost of handling in distributing system, per ton	0.0440	0.0494
	Operating expense—Boiler equipment		
84.	Total investment (items 52, 53, 54, 55, 56, 57, and 58)	$1,810,000	$2,018,000
85.	Interest at 7% on item 84	126,700	141,260
86.	Depreciation at 5% on item 52	....	....
87.	Depreciation at 10% on item 53	24,000	48,700
88.	Depreciation of furnaces	see item 97	see item 97
89.	Depreciation at 10% on item 56	2,000	6,500
90.	Depreciation at 10% on item 57	1,000	1,000
91.	Taxes and insurance at 2% on items 52, 53, 55, 56, 57, and 58	34,520	40,360
92.	Total fixed charges on item 84	188,220	237,820
93.	Total fixed charges on item 84 per ton fired (item 92 ÷ item 46)	0.40	0.46
94.	Cost of electric power per ton fired	0.015	0.069
95.	Cost of maintenance per ton fired	0.02	0.14
96.	Cost of lubricants per ton fired	0.002	0.001
97.	Cost of furnace repairs per ton fired	0.04	0.03
98.	Cost of labor, including ash handling, per ton fired	0.0606	0.0933
99.	Total cost of boiler firing, per ton fired	0.5376	0.7933
	Operating Expense—Total		
100.	Total cost of preparing, distributing, and firing coal per net ton (items 71, 83, and 99)	0.9141	0.8517

DISCUSSION

Mr. A. L. Hoerr, *Chairman*:* The paper to which you have just listened contains a great deal of interesting and valuable information about powdered coal. The combustion of any fuel is, of course, governed by rather definite laws; but, when you come to applying fuel to any particular industrial or metallurgical process, you run into things that are not quite according to these general laws, and therein lies the difficulty of using the various fuels we have available.

I have seen a large number of installations of powdered coal, in puddle furnaces, various kinds of heating furnaces, and boiler furnaces. I have heard them highly praised and I have heard them roundly condemned. I have seen a plant in which the coal is powdered at a central point and distributed over a considerable number of consuming units where it is claimed to have been done with perfect success. I have seen it used in a continuous heating furnace where the man said, "If I only could, I would throw it out to-morrow and go back to gas-producers," and I have seen some installations where the men say they would not be without it for anything, which seems to bear out what the speaker has said, that each installation is an individual problem, just as it is in burning lump or slack coal.

I was at one time about convinced that powdered coal was no good at all because of some advocates who urged it upon us for every conceivable purpose, regardless of our coal cost or what we wanted to do with the heat, and it was not until after looking the thing over thoroughly that I began to admit that perhaps there was some virtue in it.

Mr. W. E. Symons:† I just happened to be in Pittsburgh this evening, and being unengaged at the hotel I started over in the direction of what I thought was the meeting room of the Engineers' Society of Western Pennsylvania, where I had the

*Chief Engineer, National Tube Co., McKeesport, Pa.
†Consulting Engineer, Galena-Signal Oil Co., New York.

pleasure of meeting many engineers some months ago. After reaching this room, I learned that an old friend of mine, Mr. Muhlfeld, was addressing the meeting. I did not hear the earlier part of his paper. I don't know what he said to you in the forepart of it, but no matter what he did say, I can indorse it without hearing it, because during my acquaintance with him I know he has always told the truth, and he is master of his subject.

The fuel situation is a very important one, and in many communities where there is plenty of fuel of any particular kind, those who are competent to advise better means and higher degrees of efficiency are liable to get a little bit stale and sleep on the job, owing to the plentiful quantity of fuel.

If you will pardon a reference to myself, I have in the last six or seven months traveled between nineteen and twenty thousand miles in connection with fuel matters. I have made an examination and report on the fuel situation in France, just returning from there to this country. I just came back from California, making a nine-thousand mile trip there, and as a result of that I have reached that mental condition in which I am ready to agree with such propositions as have been presented to you here this evening, that although we are living in a coal country, or an oil country, or a gas country, we should not stop and sit still, as it were, and be content with what might be termed fairly good results. We should strive for higher degrees of efficiency, because the fuel supply will not last forever. There is a limit to it, and while we have a plentiful supply we should devise means of using it more economically.

I might say that one particular angle of my study recently has been with respect to fuel oil, which it is contemplated will be imported into France in considerable quantities within the next two or three years, as the French people mine about forty-two million tons of coal and import about twenty million, making sixty million tons. They need now, this year, eighty million tons. They have what we call "in sight" about thirty-eight or forty million tons, therefore they must get fuel somewhere else. They cannot get coal from England, bceause for her own requirements England is mining at a reduction of about forty-three per cent. The United States cannot give them coal. They cannot work

their mines in France for lack of man power. The same is true of the Saar valley. It seems that the direction of immediate relief lies in getting fuel oil, which can be handled with a minimum of man power, as described by the author with respect to powdered coal.

Most people, however, who have not burned it, are afraid of fuel oil. In New York City some months ago it was proposed to introduce fuel oil and a committee of representative citizens went before the Board of Alderman and said to them, "You will do our city irreparable injury if you allow oil to come in to be burned; your insurance rates will go up out of sight; it would be dangerous; you are liable to burn down the city." That, of course, was an unwarranted scare, with no grounds for it at all. In San Francisco, I personally know of numerous fuel oil installations that were put in prior to the fire and earthquake of 1906. After the fire had destroyed the city—which was largely built of concrete and brick—in erecting new buildings they put in fuel oil and in many cases connected to the same oil reservoirs that were used before the fire.

I thoroughly agree with the author with respect to furnace design.

I have frequently found much time, energy, and money spent on patent burners, when really what was needed was a furnace design suitable for the fuel to be used.

From my observation, it seems to me that in large plants there is a field for powdered fuel and for the use of fuel oil; and, undoubtedly in the small plants, where it would not justify the expenditure for a powdered fuel installation, liquid fuel is the proper solution. Liquid fuel devices are operated satisfactorily by people who have absolutely no engineering knowledge whatever. As an illustration, in a large theater in San Francisco a few weeks ago, I said, "I want to see the engineer, the man who runs this oil fuel plant." They brought me a man and I said to him, "What business were you in before this?" and he said, "Shining shoes." "How long have you been running this plant?" "Six months." "How do you operate it?" He explained just how he started it, how he ran it and how it automatically shut itself off. I also inquired of the management and

was told that there had never been an accident nor any failure to have heat.

In another case in a large restaurant in Seattle, where at the noon hour they have possibly three to five hundred people, they had an oil burning device for their large range. I asked who was the engineer in charge, and was informed that the second cook ran it. I went to see him and said, "Do you run this outfit?" He said, "I do when I feel like it." "When you don't feel like it, who runs it?" "The dishwasher." "Suppose the dishwasher doesn't feel like it?" "One of the waiters runs it." So we need have no fear about handling these devices used for liquid fuel, and I am satisfied that any device that Mr. Muhlfeld recommends for powdered fuel comes within the zone of efficiency and safety.

The time will come when we will be sorry we did not sooner begin conserving our fuel. The natural gas supply is diminishing every year. Of course, one way in which we can conserve is to stop burning bituminous coal under boilers for making steam. Every ton of bituminous coal contains about 60 or 70 pounds of sulphate of ammonia; and the total, if applied as a top dressing to our lands, would increase the yield of wheat, corn, oats, and so forth into the millions of bushels. We can also secure about 120 pounds of tar from each ton. That coal can be made into producer gas and we can produce electricity using internal combustion engines, and thus save millions of dollars worth of sulphate of ammonia and tar now wasted under boilers; or we can crush the coal and burn it in the form recommended by the speaker of the evening.

Mr. J. H. Richardson:* I came in here this evening ust as Mr. Symons did. I happened to be in town on structural work connected with a coke plant which makes coke from powdered coal, or will do so this summer. This coal is put into retorts similar in form to ordinary coke retorts; but, being powdered, it is forced through continuously from the receiving end by revolving paddles on a revolving shaft about 16 inches long. This

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keeps the powdered coal moving and during its passage through the retorts it becomes coke. The retorts are fired by the gas produced, and all the by-products are possibly going to be saved. The object is to save a large percentage of the products, such as tar, ammonia, etc. The experimental plant is at Evington, near Jersey City, N. J. I believe they have had very good success with the process.

Mr. O. P. Hood:* It seems that this meeting is turning into an experience meeting of strangers and visitors. In times past I have seen a number of meetings of this Society start in this way, and yet, before we got through, it was perfectly evident that every fellow present was loaded with information or suggestions, and I rather suspect the same thing to-night.

I have but little to say on the matter of powdered coal. One of the first statements made by the author of the evening was that any one in the boiler room who had burned powdered coal and had also burned solid fuel, if asked which he would prefer, would be sure to take powdered coal. The author did not include the man who runs the powdered coal plant, I believe. The point I want to make is that it is always delightful to see the simplicity of apparatus in the boiler room, burning powdered coal, but when you get into the plant where you are preparing it, it is sometimes a little different.

It is a pity that so valuable a means of using coal should have to be restricted to those plants that are using something like 80 tons per day, because, while the United States Bureau of Mines is interested in the general problems of combustion, we still have to keep an eye open to the great public—the numerous small users who cannot afford expensive equipment.

I was particularly interested in an experiment going on in Seattle—the experiment of pulverizing coal in a central plant and distributing it to the small user. The delivery scheme as evolved through a number of steps seems to be quite successful. They are delivering powdered coal in much the same way that they would deliver oil. It is delivered in closed tanks. It flows into a container in the cellar very much as oil would flow, and

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this makes it possible for the small user to realize such advantages as there may be in the use of powdered coal. These plants had, however, found an ash nuisance that was somewhat comparable to the smoke nuisance. They came to the conclusion that until some better means was developed for taking care of the ash problem, they hardly felt like pushing powdered coal for these moderate-sized plants.

MR. A. L. HOERR, *Chairman*: At one plant where powdered coal was being used right in the midst of a considerable residence section, I made it a point to go around the houses and inquire whether or not they had noticed any general distribution of ash over the surrounding territory. I thought the housewives would be very keen to see it if there was. I could find no complaints of that sort; but I did hear complaints, at another place, about the distribution of fine ash in the immediate vicinity of the plant, and I am sure that unless special precautions are taken this is bound to occur.

MR. A. E. BLAKE:* I am surprised to find that 80 tons is the minimum capacity for economic operation. I had understood that there had been types of apparatus gotten out to work on individual furnaces. Perhaps Mr. Muhlfeld can tell us something of them.

MR. JOHN E. MUHLFELD: The reason I put a limitation of 80 tons is that we have found that the investment cost largely governs an undertaking of this kind. When it comes to the small self-contained equipments, I know quite a number have been used and, having investigated them, we found that the maintenance cost of the smaller unit, particularly the high-speed unit, was exceptionally high, and that in various cases they had been removed on account of the excessive maintenance cost. When you take a plant of about two tons an hour capacity, running two 10-hour shifts during each 24-hour period, that is about the limit of economical investment, and if you go lower than that the investment is hardly justified by the saving through the use of

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powdered coal. This conclusion is the result of a great many tentative propositions that have been worked up, and from installations that have actually been made. You can hardly justify anything on a smaller basis, if you include overall expense, which includes not only fixed charges but also the operating items.

Mr. W. E. Symons: Having been raised a Quaker, probably I can live up to the Quaker traditions in everything except keeping still. I will add just a few more words to what I have said.

I see in the possibility of powdered fuel, particularly here, in this coal district, an angle that I think is clearly implied in the author's paper, and that is, that a tremendous saving could be effected by taking care of the fuel now wasted in small quantities in thousands of places, and larger quantities in a smaller number of places, that could be used in one large plant—consuming 80 tons a day, or more—that could furnish power or steam for more than one user. The individual or small consumer that might have in mind powdered fuel, but could not justify the expense, could then use gas or oil. The amount of coal now used by hundreds and hundreds of small consumers, if all combined, crushed, and used in one large plant, would constitute a plant which could be operated economically, the overhead, depreciation, etc., properly taken care of, and in that way you would conserve your natural resources. I do not think it is intended that powdered coal should be prepared and used by the small consumer.

I am sorry I did not inspect the plant in Seattle. I know it is in operation and the coal is being delivered in the manner previously mentioned. There is a little complaint with respect to a very fine, hazy, rusty colored smoke that sometimes comes from the stacks, but I think this complaint came largely from those who have been burning oil, are not used to smoke and could not find anything else to talk about, and have probably slightly exaggerated the matter.

As an illustration of the feeling of people who have changed from burning coal in bulk, I will mention what was said to me by the manager of a hotel in San Francisco. He had been burning oil for years—and I think if he had been burning powdered coal

he would have felt about the same with respect to changing from lump coal. He had been using oil a number of years, and I said, "What inducement would a coal man have to make to you with respect to price to get you to change back from oil to coal?" "Why," he said, "for the first few months after we changed, we naturally compared our cost sheets between coal and oil, but for years we have not thought of coal at all; to be frank, we would not have the damn stuff in here at any price." "Now," I said, "I have made a little study of this subject and I am going to write down one item on a piece of paper—one of the reasons why I believe you would not change, and I will hand you that paper folded, and after you tell me your reasons I wish you would open that piece of paper and read what I have written on it. Now I wish you would tell me your principal reason." I wrote on that piece of paper that the extra cost to a hotel of that size in laundering linens, taking care of tapestry, carpets, paint, pictures, etc., would amount to probably twenty to twenty-five thousand dollars a year. His answer was, "Among other things our laundry bill would be fifteen thousand dollars more than it is now." I said, "All right, just unfold that paper." His answer was just what I thought it would be, because I had learned that from some others I had talked to. In Chicago, it is estimated by the merchants on State Street that their loss is ten to fifteen million dollars a year from coal dust settling on their fine silks and satins, curtains and fabrics. The coal dust comes in the store and injures these goods and they have to put them on the bargain counter at a great loss. I inspected many plants burning oil. The smallest one was a seven-room residence in which the oil bill was $17 a year. One of the largest ones was the Western Heat and Power Company, where the fuel bill was $230,000 a year, and none of them would consider changing back to lump coal at any price. One of the principal objections, next to handling, is constant annoyance from coal cinders and ash dust. With liquid fuel you are entirely free from that.

Mr. A. E. Blake: A good deal has been printed lately about using mine waste. Can Mr. Muhlfeld give us any information as to how to utilize coal that is too poor to go on the grate,

and also tell us what he considers the limiting ash content for solid powdered fuel?

As regards the dust nuisance, I think it would be of considerable interest to investigate some of the propositions for removing dust electrically. Some excellent work has been done in that line at Mellon Institute, and the results are a matter of record. It was found that ash dust can be cleaned up much more easily than soot.

Mr. John E. Muhlfeld: Regarding the utilization of mining by-products, a great deal of work has been done in that direction. I know of one case, where changes were made in a certain plant for the purpose of utilizing the anthracite dust that is now being dumped in large tonnage into streams and rivers and back into the mines. It was finally developed that this fine anthracite dust, which runs all the way from 16 to 31 per cent. ash, from 1 to 5 per cent. sulphur, and from 8000 to 12,000 B.t.u. could be utilized very efficiently with certain furnace constructions. However, with low volatile coal such as anthracite, you have to have a relatively continuous furnace operation to get the best results from furnace wall radiation and, furthermore, as the cost of grinding is somewhat higher than for soft coal, that is also a factor for consideration in the final result. Delay in making installations for anthracite by-products has been due both to the war, and on account of determining methods that are best adapted to reclaim the dust. When these methods have been worked out, I think you will find that a lot of this by-product will be utilized, particularly in the anthracite district in combination with central power stations located in the vicinity of the collieries.

Mr. O. P. Hood: The situation in the State of Washington is a little peculiar in that about 50 per cent. of the coal, as mined, will go through a ¼-inch screen, so that the remaining lump coal has to bear almost the whole cost of mining. It is, therefore, high in price. There is a comparatively small amount of use for this fine coal. This is a perfectly natural place, therefore, to apply powdered coal, even if little or no attention were paid to efficiency of combustion. The coal is very high in ash, somewhere in the neighborhood of 20 per cent. The largest coal

company there is greatly interested in finding an outlet for these fine sizes of coal.

Powdered coal was introduced into the very large plants, and also in some smaller plants such as laundries, small hotels, and plants running from 20 to 80 horse-power. The smaller plants were in the business district and, naturally, they had relatively short stacks. It was those short stacks in a rather crowded district in combination with the relatively high percentage of ash that made the ash nuisance noticeable. They would have done better, perhaps, if they had restricted the experiment to the large plants that had high stacks, or to the small residences where it would be more widely distributed and where the quantity would be so small that it would hardly be noticed.

There are a great many fuel burning schemes just now. I know of one man, who the latter part of last winter, heated his small house with powdered coal. His vision was that if he could develop a small stoker that would use powdered coal, the housewife, when she ordered a peck of potatoes and a sack of flour would also order a sack of powdered coal from the grocer. This sack of coal would be placed in the stoker device which would keep the house warm for a day or two. A question was raised as to whether the powdered coal would not absorb moisture, and interfere with its use in an automatic device. Five sacks of powdered coal were put up in the ordinary paper sacks that are used for flour. These sacks were sent by express to Oakland, Calif., and put on a back porch for about five weeks in the rainy season, and then shipped back to Chicago by express. The coal was still dry, still usable, and was used in a little stoker under thermostatic control. This goes to show one of the possibilities of powdered coal.

Mr. John E. Muhlfeld: I want to thank Mr. Symons for dropping in and for his complimentary remarks. I am rather disappointed by the lack of criticism in the discussion. There is evidently some lack of interest in the subject or in the speaker, as the paper has not brought out the discussion I expected it would in this district.

In regard to preparation plants for powdered coal, I want

to say that, from my knowledge of the pulverizing and drying equipment on the market, it has been a sort of evolution from apparatus which was originally designed and put into use for entirely different purposes and which required adaptation to coal and lignite grinding.

I think Mr. Hood is fully justified in the criticism he has made of the preparation plants; not only in regard to the equipment we have had to use, but also regarding the power required. I can frankly state, however, that some of the manufacturers of this equipment have been very ready to take advantage of suggestions offered, and are now going ahead with refinements for the purpose of better adapting their apparatus to the powdering of coal. They are also developing the production of larger units. When it comes to large installations, the existing sizes of pulverizers require too many units and too much power for their operation.

In regard to the ash nuisance from the low chimney installations for apartment houses and office buildings, I think the proposition Mr. Hood mentions is very probable. No doubt in those installations the system used requires a blast in the furnace, which in my opinion is entirely wrong. With systems having furnaces designed with "hot" and "cold" zones into, or through, which the solid non-combustibles can be passed; and where the air blast is dissipated before it reaches the combustion zone, and with less than 0.05 inch of water draft in the furnace, this ash nuisance would be eliminated.

Another point in regard to the ash, when pulverized coal is used in large boiler installations. I know of one in Milwaukee, in the central business district, where tests have been made to determine the relative quantity and quality of smoke, ash, and gases emitted from the stacks, and, so far as I know, no complaints have ever been made. Of course, in this case the furnaces are relatively large units and strictly designed for powdered coal with plenty of flame-way and stacks of the usual height for plants of that kind.

In regard to distributing powdered coal in barrel lots to small users, I do not see any reason why a central pulverizing and supply plant could not be installed. I think some day that will come about, and I see no reason why it should not.

THE PRESENT STATUS OF THE THEORY OF THE ROLLING-MILL

By W. Trinks*

The Engineers' Society of Western Pennsylvania is located in the center of the largest industrial district of the world, where we "make iron and steel" for a living. Our rivers are lined with rolling-mills, and yet very, very few papers have been presented to our Society on the theory of the rolling-mill.

Not that there is no theory to the rolling-mill. Quite on the contrary, the theory is so deep and complicated that it has never been worked out. To put it differently, the absence of rolling-mill papers may be caused by the fact that engineers have hesitated to admit how little our profession really knows about the theory of the rolling-mill.

A complete theory would have to deal with:

1. The forces between the stock and the rolls.
2. The deformation of the stock.
3. The effect of the forces upon the mill.

Items 1 and 2 are interdependent, because the forces are the result of the resistance which the stock offers to deformation. For that reason, it will pay us to review briefly our knowledge of the laws of plastic deformations. The differential equations of plastic deformations were written by de Saint-Venant (*Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences*, 1870, vol. 70, p. 473, and by Reynolds (*Philosophical Transactions of the Royal Society of London*, 1876, vol. 166, pt. 1, p. 155). Both of these eminent scientists were forced to admit that these equations cannot be integrated. This admission need not cause any wonder, because, compared to elastic deformation, plastic deformations have a disturbing term—namely, the time effect of viscosity, or internal friction. Engineers who have tried to integrate the differential equations of elastic deformations in three dimensions will realize the unsurmountable difficulties which pile up if a viscosity term enters.

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In spite of this poor outlook for a mathematical solution of the problem, the underlying elementary principles of plastic flow should be better known to rolling-mill engineers. The laws are these: Flow takes place in the direction of greatest shear. For a given condition of the material, the velocity of flow is proportional to the difference between actual shearing stress and yield-point shearing stress (See Fig. 1). From this behavior of the

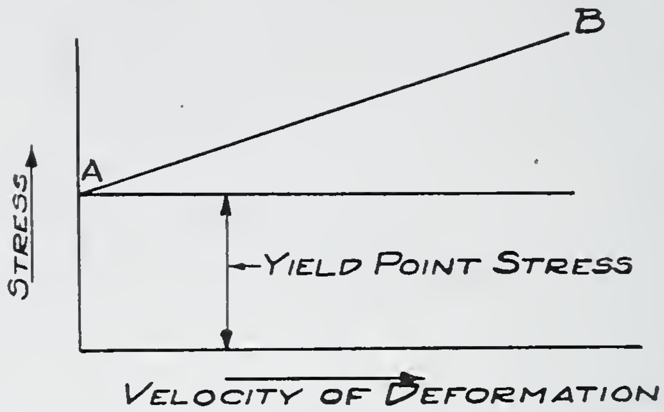

Fig. 1. Ideal Stress-Velocity Diagram for Plastic Materials.

steel, it follows that slow rolling produces lesser stresses in steel than does fast rolling. The case is parallel to that of a bar of pitch, which will bend slowly under the action of a sustained small force, but will break under a greater force. Viscosity also has the effect that fast rolling requires more work per unit weight of steel than very slow rolling does. As the velocity of deformation increases, the line, *AB,* curves downward as indicated in Fig. 2. There are two reasons for the curvature. The greater force required by higher speed means that more work is put into the steel and that its temperature rises, this, in turn, causing the viscosity to drop. Also, the higher pressure causes the material to approach the point at which liquefaction due to combined temperature and pressure occurs. In consequence, the pressure cannot rise higher. The values of Fig. 2 should not be

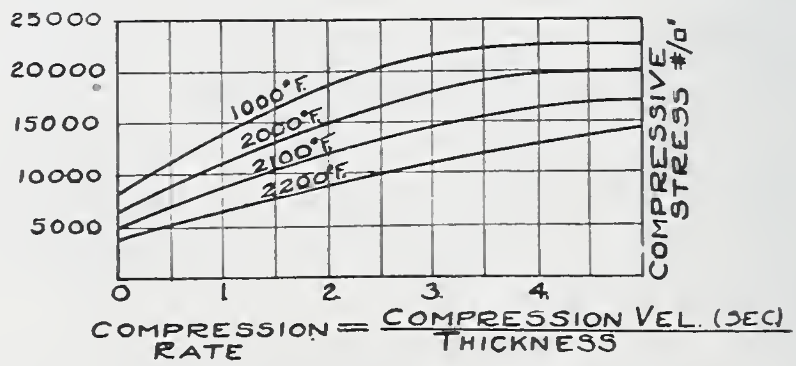

Fig. 2. Practical Stress-Velocity Diagram for Hot Steel.

considered final, because they are founded on a few rather crude test data. More accurate tests on this problem are very much to be desired.

The abscissæ in Fig. 2 will require some explanation. They represent the time rate of unit compression, or the compression velocity. The value of 3 would literally mean that a bar is compressed three times the amount of its initial thickness in one second. Such a compression is physically impossible, but it is quite possible to compress the bar 0.3 of its original thickness in 0.1 of a second, and 0.3 divided by 0.1 equals 3.

That rolling below a certain speed saves in power is known to many mill engineers. They also know that it produces better steel, because the stresses caused by slow deformation of viscous solids are less than those caused by quick deformation.

This consideration brings us to another question of greatest importance to the rolling-mill man—namely, how much deformation can a plastic substance undergo without injury to the material? The answer is that the permissible amount of deformation is unlimited, if the material is always under compression from all sides (hydraulic compression). This may seem strange, because the statement is made without regard to the ductility of the material, but the statement is nevertheless true. It will become plausible if we remember that layers of brittle rock are bent underground without breaking, because the material is subjected to pressure from all sides. It is made even clearer by a study of Fig. 3 which shows a column of brittle marble which was compressed when subjected to a hydraulic pressure from all sides (*Zeitschrift des Vereines deutscher Ingenieure*, 1911, vol. 55, p. 1749). However, there is this difference with regard to ductility. Each and every material has a critical temperature below which it is hardened by deformation (cold flow) and above which it is not hardened (hot flow). A cold flow limits the additional deformation which the material can stand after cessation of the initial deformation. By far the greatest number of rolling-mill deformations belongs in the second class—that of the hot flow. In consequence, there is no limit to the deformation without injury to the material, if tension be avoided, but tension can hardly ever be avoided in rolling, as will be proven subsequently. The effect

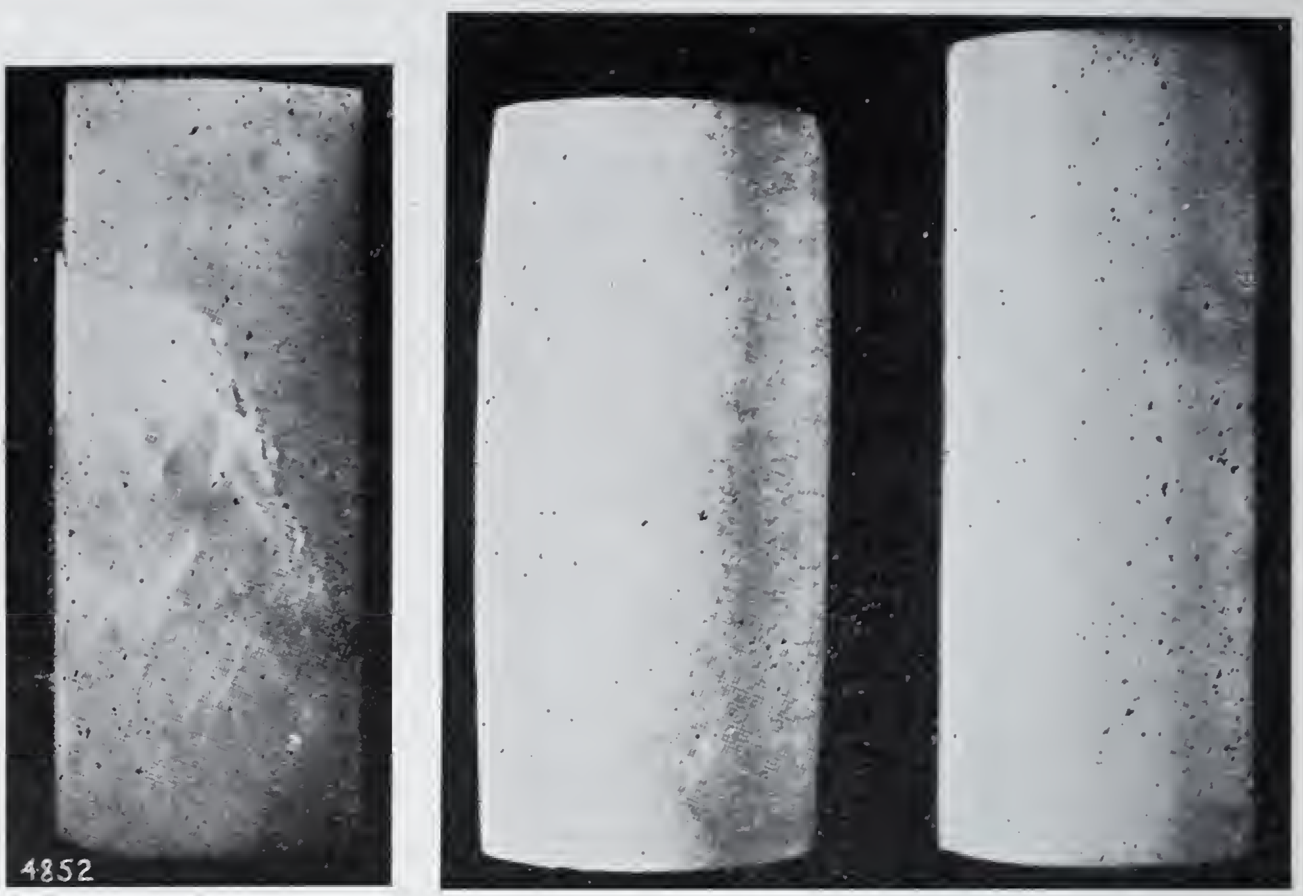

Fig. 3. Compression Test on Marble, Proving That Brittle Materials Become Plastic under Hydraulic Compression.

of tension is measured by the unit or specific elongation which accompanies it. The amount of unit elongation which is allowable in rolling varies with the quality of the material, with the ratio of absolute rolling temperature to absolute melting temperature, and with the velocity of elongation. Whether lateral contraction can or can not occur, likewise affects the maximum permissible elongation. Cases are on record in which steel was cracked under a unit elongation by tension of only 2½; while, in other cases, tensile elongations of 7 and 8 did not injure the steel. What information we have on this subject comes from incidental observations taken from practice. No well planned tests have ever been published, as far as I know. A great deal remains to be done in that direction.

Turning to the forces which flow between the steel and the rolls, we find a great confusion of ideas. Most people think that the steel is "pulled through the rolls" with great force. As a matter of fact, there is very little, if any, pulling action. If, in Fig. 4, we imagine a bar, *1*, passing through the rolls, *2* and *3*, then

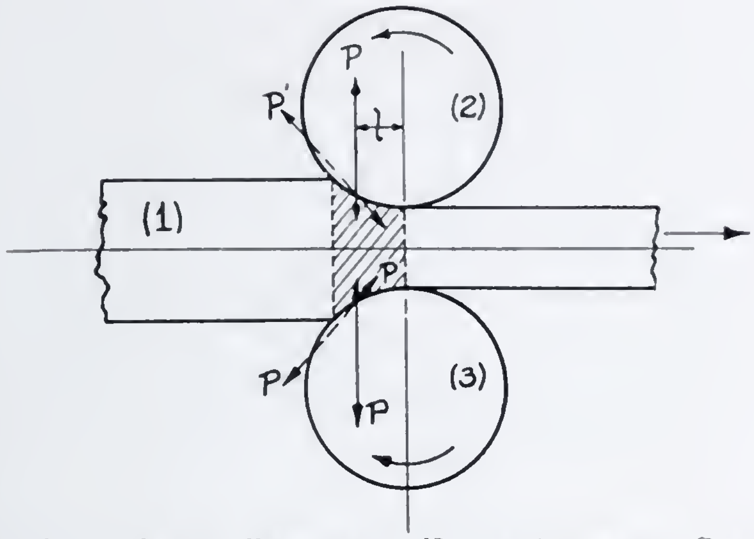

Fig. 4. Direction of the Resultant Force between Steel and Rolls.

the resulting forces, P, must be at right angles to the direction of rolling if the bar is free to move. The proof for this statement is best given indirectly. If the resultant were inclined as shown by the dotted lines, P', there would be a horizontal component pushing the bar to the right; but, by assumption, the bar is free, so that there is no force to take up the horizontal component of the force, except that caused by the inertia of the bar. Acceleration would result and the bar would go faster and faster. This, it does not do, hence the force P must be vertical.

There are a few qualifications to this statement. The section lined material changes its state of motion. It is being accelerated and, in consequence, requires a small horizontal component which is, however, negligibly small, compared to the other forces. If the speed of the mill changes, as in reversing mills, there is a horizontal component. There also exists such a component when a piece first enters the mill. Finally, we have horizontal components in continuous mills with several stands.

While it is a comparatively simple matter to determine the direction of the resultant force between the steel and the rolls, it is absolutely impossible to determine the distribution of the force elements of which the resultant force is built up. In order to test our present-day knowledge of this distribution, let us study the rolling of a rectangular section in a flat open pass (bull head). (See Fig. 5.) It is immediately evident that section *3-4* leaves with a greater speed than that with which section *1-2* enters. This difference in speed of flow can be brought about in two ways. Either the surface of the steel in contact with the roll has a var-

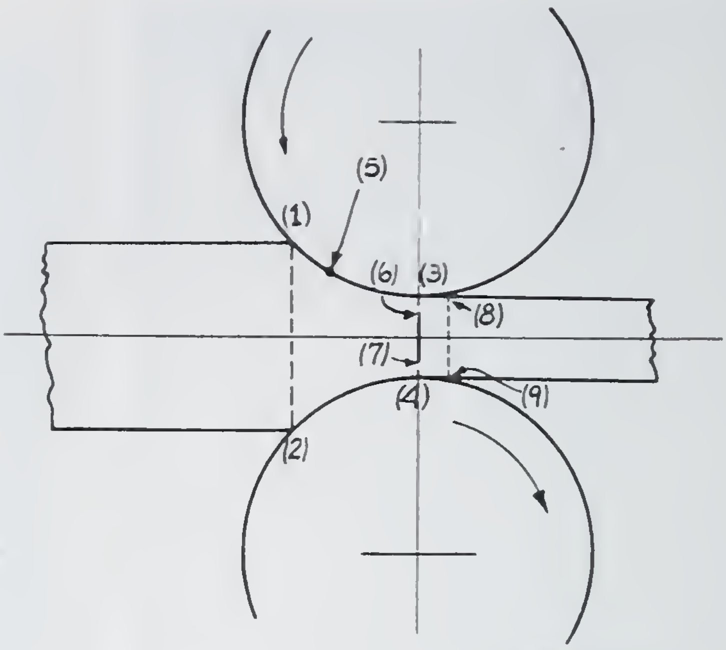

Fig. 5. Direction of Force Elements between Steel and Rolls.

iable speed, the latter coinciding at some point, say point *5*, with the surface speed of the roll and differing from it at all other points, or else the steel surface in contact with the roll has at all points the same speed which the roll has. If the former occurs, then the steel lags behind the roll over the distance *1-5*, and slips ahead of it over the distance *1-3*, causing considerable friction and wear; but, if the second possibility occurs, then all sliding must occur within the steel. The particles within the section *6-7* would have to go faster than those in the section *3-6* and *4-7*, whereas in an adjacent section, *8-9*, the particles would have uniform velocity. This is improbable, and it stands to reason that the first named distribution of velocities is the more likely to occur.

As a matter of fact, actual distributions of velocities frequently lie between the two extreme possibilities. We find, for instance, that in the edging passes of wide slabs (Fig. 6), the

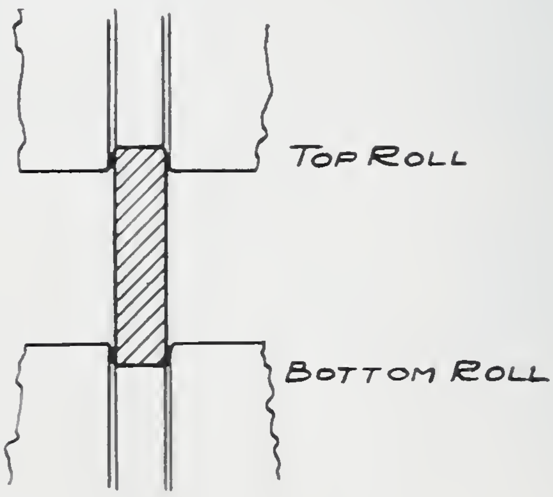

Fig. 6. Edging Pass.

slab surface can have the velocity of the roll surface over a large part of the arc of contact, because the section is deep in comparison to the reduction and, therefore, allows flow in the interior of the steel much more readily than a shallow section would do.

In by far the greatest number of cases of rolling, there is slippage between the steel and the rolls. There is a certain center of grip (point *5*, Fig. 5 and 7) at which the steel and the rolls have the same speed. Between points *1* and *5*, frictional components tend to hold the roll back, while between points *5* and *3*, frictional components tend to push the roll ahead. For that reason, the distribution of forces in the rolling process is quite different from the distribution which establishes itself when steel is compressed between the platens of a press. In the latter case, pyramids or cones are formed (*1-2-3* and *4-5-6* of Fig. 8) inside of which deformation is hindered by the friction between deformable material and the platen, and outside of which the deformation goes on with greater ease.

Ever since about 1880, German writers on the theory of the rolling-mill have tried to make engineers believe that similar pyramids or prisms exist in rolling (see bottom half of Fig. 7), but

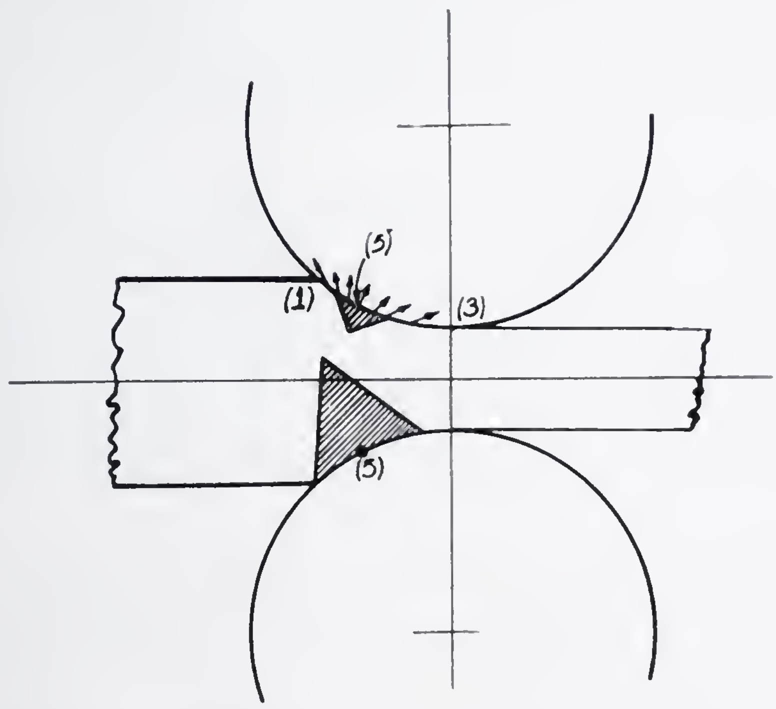

Fig. 7. Diagram Illustrating the Possibility of Friction Prisms within the Steel.

I cannot share that view, because the existence of friction pyramids is dependent upon the absence of slippage between rigid

material and plastic material. If such prisms exist, they must be limited to a very small region at or around the point of grip at 5, in Fig. 7.

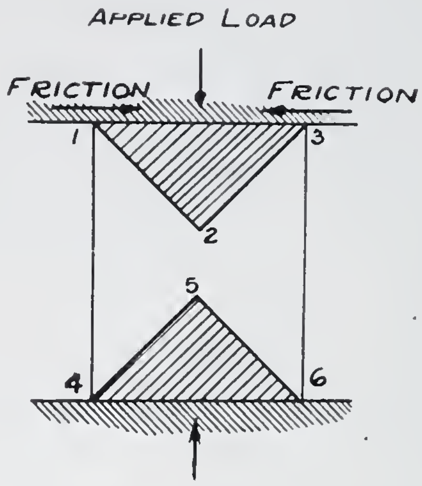

Fig. 8. Friction Cones in a Cylinder Subjected to Compression.

It would be exceedingly interesting to follow this problem further, investigating under what conditions the steel leaves the rolls with velocity in excess of that of the rolls—which phenomenon I call forward slippage. Evidently, roughness of the rolls, reduction, thickness of the steel, temperature of the steel, and other, but minor, influences must enter into the consideration. But such an investigation would be based principally on conjectures, because there are not sufficient experimental data available for a reliable theory.

Returning to Fig. 4, we must realize that we have determined only the direction of the resultant force between rolls and plastic material, but have not yet determined its line of action—that is to say, its point of application—and in attempting to do so, we find how little we really know about the distribution of forces in the mill.

We cannot integrate the force elements in Fig. 7, because we cannot locate them either analytically or graphically. We might try to get the line of action experimentally from the work per revolution, because $W = 2 \pi P l$, where W equals work per revolution, P the resultant force, and l its lever arm; but such attempts are fruitless on account of roll-neck friction. The tremendous influence of the latter is not sufficiently realized by roll-

ing-mill men. In order to obtain an idea of the part which it plays, let us form the ratio of

$$\frac{\text{pure rolling work}}{\text{pure rolling work} + \text{roll-neck friction work}}$$

for one revolution of the mill. Then we have:

$$\frac{2\ \pi \times 0.7a\ P}{2\ \pi \times 0.7a\ P + f\ P\ 2\ \pi\ d} = \frac{1}{1 + f\ \frac{d\ 1}{0.7a}}$$

where f is the coefficient of friction between the roll-neck and the brass. The rest of the notations are clear from Fig. 9. On ac-

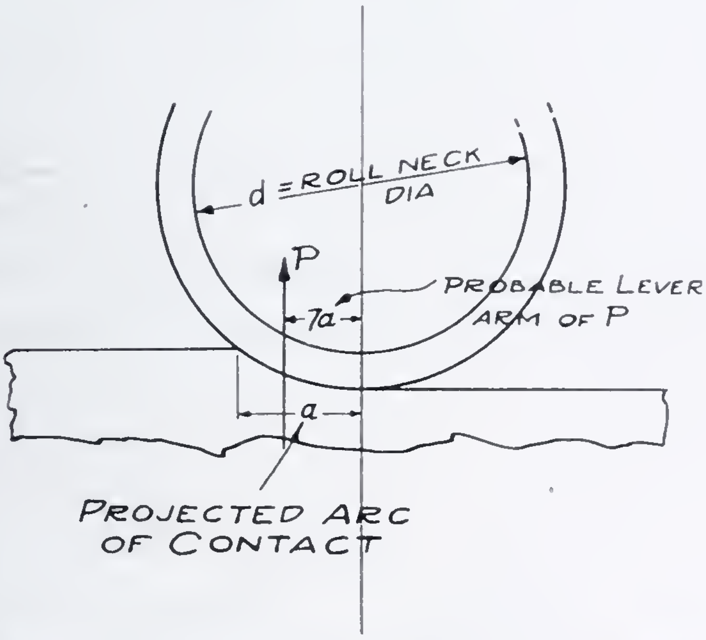

Fig. 9. Diagram Illustrating the Effect of Roll-Neck Friction.

count of the magnitude and the variability of the force P, the coefficient of roll-neck friction varies all the way from 10 to 25 per cent. By substitution of the extreme ratios of d/a from blooming-mill practice at one extreme, and from cold (sheet) mill practice at the other extreme, we find that roll-neck friction accounts for from 35 to 90 per cent. of the resistance to rolling, the former value holding for blooming mills, the latter value holding for cold mills. In the operation of cold mills there is scarcely any change in the power requirement between the operation of the mill running idle or working.

Evidently, we cannot determine the line of action of the resultant force, P, from the work per revolution unless we can

separate the pure rolling work from the neck friction work, and, as far as I know, this latter feat has never been accomplished experimentally. I have designed apparatus for separating these work items, but have never had an opportunity to apply it. It is obvious that with 90 per cent. of the power input wasted in friction, any research to study this loss should be welcome. However, rolling-mill managers do not seem to worry about the loss, because they can pass the cost on to the "ultimate consumer."

From the above ratio of pure rolling work to total work, it follows by a simple algebraic transformation that, for a given draft, small rolls use less power than large rolls. From the form of the expression it also follows that the relation is complicated by the variability of the roll-neck friction coefficient. Various rules have been given stating that roll-neck friction grows either with the square root of roll diameter or with the cube root of the roll diameter. These rules are nothing but empirical guides for the memory, without any scientific reason, and hold true only for specific conditions and over a very small range of sizes.

Variable friction also makes predetermination of the work requirements of rolling steel most uncertain. In rolling a given weight of steel we must overcome the internal resistance of the steel, friction between steel and rolls (including collar friction), roll-neck friction, and pinion friction. The internal deformation work of the steel varies with its temperature, with its chemical composition, with its deformation, and with the ratio of thickness of steel to projected contact area (contact between steel and rolls). Any formula for roll-train resistance which is intended to be based upon correct principles must take all of these variables into account; but we are not far enough along to develop such a formula. We help ourselves by making up a rather arbitrary formula for the work of deformation and account for all of the other work by a widely variable, stop-gap coefficient, which some engineers, in a rather optimistic manner, call a "constant."

Two such formulæ are used in practice. One is the displaced-volume formula, and the other is the logarithmic formula. The former is based upon the view that in rolling, the section-lined volume $(A_1 - A_2) \times L_1$ (Fig. 10) is removed from the top of the bar and is added to its length in the shape of $A_2\ (L_2 - L_1)$.

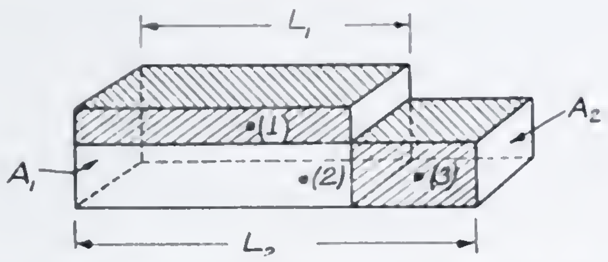

Fig. 10. Diagram Illustrating the Displacing of Volume in Rolling.

This view considers that "pigs is pigs," or that steel is steel, no matter where it is located. As a matter of fact, a point, *1*, belonging to the bar before the rolling, moves to point *2* during the rolling, and does not move to point *3* as the displaced volume theory would indicate.

Nevertheless, the displaced volume furnishes a simple measure for the amount of work done per pass, and we write work required for rolling $= k$ times the displaced volume, when k is the aforesaid variable coefficient.

A second formula is based upon the continued compression of a bar, as shown diagramatically in Fig. 8. If S is the yield-point stress of the bar, then the force, P, needed for compression is,

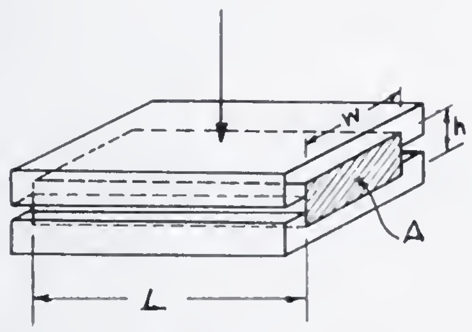

Fig. 11. Diagram Illustrating Continuous Compression in Rolling.

$$P = S\ W\ L,$$

and the work of a very small compression $d\ h$ is,

$$W = S\ W\ L\ (d\ h),\text{ but,}$$

$$W\ L\ h = V,\text{ the constant volume of the bar,}$$

so that,

$$W = S\ V\ \frac{d\ h}{h},$$

and the work of compressing the bar from thickness h_1 to h_2 equals,

$$W = S\ V \log_e \frac{h_1}{h_2},$$

but the thickness ratio equals the elongation ratio if spreading is prevented, so that,

$$W = S\ V \log_e \frac{L_1}{L_2}.$$

The "displaced volume" formula can be written in a similar form:

$$W = k\ A_2\ (L_2 - L_1) = k\ A_2\ L_2\ (1 - \frac{L_1}{L_2}) = k\ V\ (1 - \frac{L_1}{L_2})$$

Evidently the value $S \log_e \frac{L_2}{L_1}$ in one formula, corresponds to the value $k\ (1 - \frac{L_1}{L_2})$ in the other formula. For a quick comparison, I have made the following tabulation:

$\frac{L_2}{L_1}$	= 1.1	1.2	1.3	1.4	1.5	1.6
$\log_e \frac{L_2}{L_1}$	= 0.095	0.182	0.262	0.336	0.405	0.47
$1 - \frac{L_1}{L_2}$	= 0.090	0.17	0.23	0.29	0.335	0.375

It is evident that for a given value of S and k the two formulæ will give almost identical results for small elongations, but that they differ considerably for great elongations.

The practical millman knows no such animal as the logarithm to the base e, but he can visualize the displaced volume. In consequence, the latter method of computing the work per pass has met with general favor. But when it comes to computing the overall work requirements for a number of passes, the logarithmic formula is preferred for the sake of convenience, because it is independent of the number of passes, and of the distribution of work over the individual passes.

We should always realize that both formulæ are nothing but convenient, conventional approximations without any pretense to theoretical correctness. From that viewpoint, it was truly comical five to ten years ago to watch two groups of rolling-mill

engineers—the "displaced-volume group" and the "logarithmic group" go at each other hammer and tongs, each group contending that it had the only true and correct formula, and that the members of the other group were little better than benighted menials.

Going more deeply into the theory of roll-train resistance is not advisable until we have the results of a series of well planned experiments in which only one element is varied at a time, while the rest of the variables are kept constant with the greatest of care.

In the early part of this paper a statement was made that a complete theory of the rolling-mill must deal with the deformation of the stock between the rolls. It had also been stated that this part of the theory is, at present, not amenable to rational analytical treatment. For that reason roll pass design—the shaping of grooves which give the desired deformation—is not an exact science, but an art. The roller, the roll turner, and sometimes the roll pass draftsman watch the deformation caused by existing roll passes, and design new ones, more or less instinctively on the basis of the existing ones. The uncertainty grows in direct proportion to the departure of the new design from the old one. There are very, very few men in the world to-day who can design a roll pass for a new shape (which has never been rolled before) on the basis of first principles.

Plastic flow of steel in the roll pass is a fascinating study in which very little can be learned from the shape of the entering bar and from the shape of the delivered bar. The piece to study is not the finished product, but the spoiled piece, which we call a cobble. The piece which stuck in the rolls contains all of the transition stages from the entering shape to the final shape and reveals the mysteries of the flow of steel better than any other. It has been said that good roll pass designers frequent the cobble pile. But cobbles which were accidentally made in commercial mills, must be used with caution, because the sustained pressure of the rolls changes the deformation from what it would have been, if the roll pressure could have been removed at once after the sticking of the bar in the rolls. See the time effect of Fig. 1.

While we must admit the present-day hopelessness of a mathematical theory of plastic deformations, we can do a great deal

by careful, analytical reasoning. Take, for instance, the problem of spreading. Most bars, when passing through the rolls, are not only lengthened, but are widened; the steel is not only elongated, but it spreads. Knowledge of the spreading is necessary, because too much spread will overfill a pass and cause fins, whereas a deficiency of spreading will cause underfilling of the pass. Various formulæ have been given for the amount of spreading, but none of them is based on rational deductions; each and every one of them is empirical. However, we can help ourselves in the following crude manner:

As the steel passes through the rolls, each particle of steel moves, under the effect of compression, in the direction of least resistance. Just what that direction is for a given particle at a given time is a puzzle, because each particle is tied by shear forces to a million others, each of which affects the motion of the rest. However, there are some features which cause steel to elongate rather than to spread; while there are others which cause it to spread rather than to elongate. One of the factors of greatest influence is what I have called the shape of the projected contact area (shown shaded in Fig. 12). If the dimension be great com-

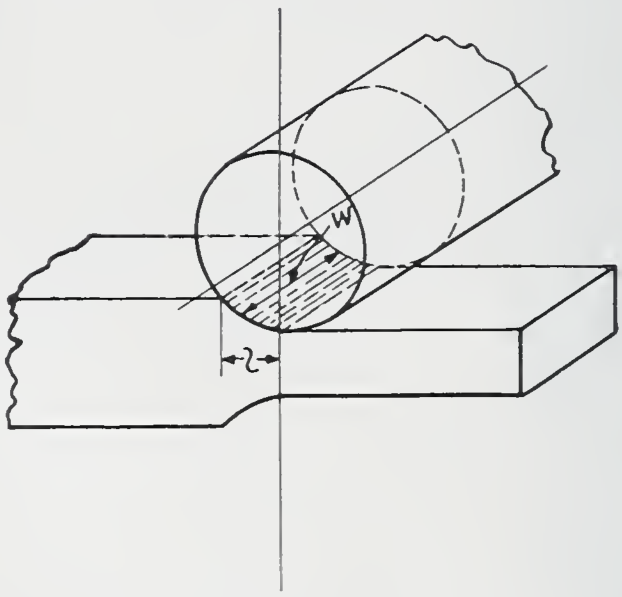

Fig. 12. Contact Area between Steel and Rolls.

pared to the dimension *W*, there will be considerable spreading, because it is much easier for the particles to escape sidewise than to slip forward against the friction of the long arc of contact. If, on the other hand, *W* be great compared to *l* there will be little or no spreading, because the latter action would have to

occur against the holding friction of the roll, whereas the short arc of contact causes very little sliding and favors elongation.

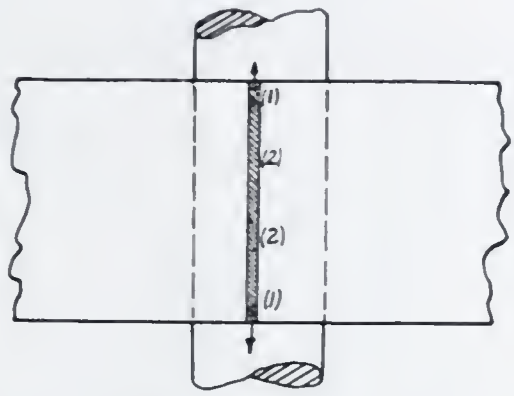

Fig. 13. Shape of the Projected Contact Area in the Rolling of Wide Material.

In such a case (Fig. 13) the compressed particles near the edges would escape laterally, if it were not for the action of the center part of the bar or plate. The elements *2* cannot escape sidewise because in doing so they would have to move all of the particles between *1* and *2*; hence, the deformation of the center is all elongation and the sides are taken along by shear. The wider the plate or strip in comparison to the roll diameter, the more pronounced is this action. Practical roll designers have the rule that spreading does not occur in strips 12 inches, or more, in width. The action is even more pronounced if the material near the extreme points *1* is not compressed, as, for instance,

Fig. 14. Negative Spreading Caused by Compression in Center Only.

in the rolling of channels. (See Fig. 14.) In this case the flanges are "pulled down," which corresponds to negative spreading. Spreading is increased by forcing the material apart by the use of wedge-shaped rolls (Fig. 15). Spreading is reduced or even prevented if the material be held together by a concave groove (Fig. 16).

To my knowledge, no rational formula for the amount of spreading has ever been published, and it stands to reason that

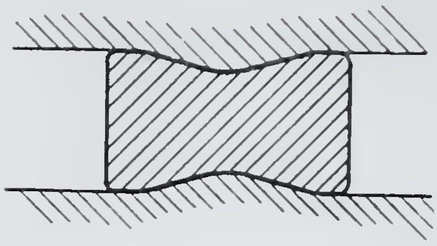

Fig. 15. Shape of Pass Increasing Spreading Action.

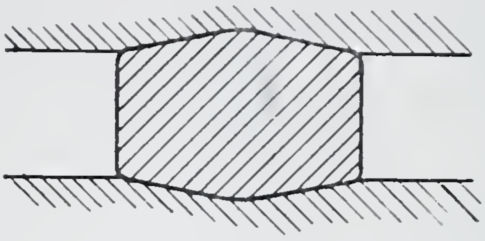

Fig. 16. Shape of Pass Hindering Spreading Action.

a correct formula would have to be extremely complicated. The statement that roll pass design is an art and not a science is therefore correct at the present time and will, I am afraid, remain so for some time to come.

What we need is a series of methodically planned tests in which cobbles are made systematically and in which the deformations are carefully analyzed.

As an example of the confusion which exists at the present time, I will mention the alleged influence of the temperature of the steel upon spreading. Practical roll turners say that cold steel spreads more than hot steel. A German investigator started out to prove or disprove this doctrine. Careful experiments showed no difference of spreading at different temperatures of the steel; yet, there must be some spark of truth in so wide-spread an impression. The explanation given by the above-mentioned investigator is this: Cold steel makes the rolls spring more, which minimizes the reduction per pass. When the steel finally arrives at the finishing pass, it is over size. The finishing rolls must be set closer together than they are for hot steel; the elongation is greater and the spreading apparently is greater.

Very few analyses of deformations in roll passes, have been published, and most of these show an astonishing lack of reasoning. In the hope of starting a discussion and securing some contributions from others who might be interested in the same field, I published in 1917 and 1918, in the *Blast Furnace and Steel Plant*, a series of sketches on the elements of roll pass design.

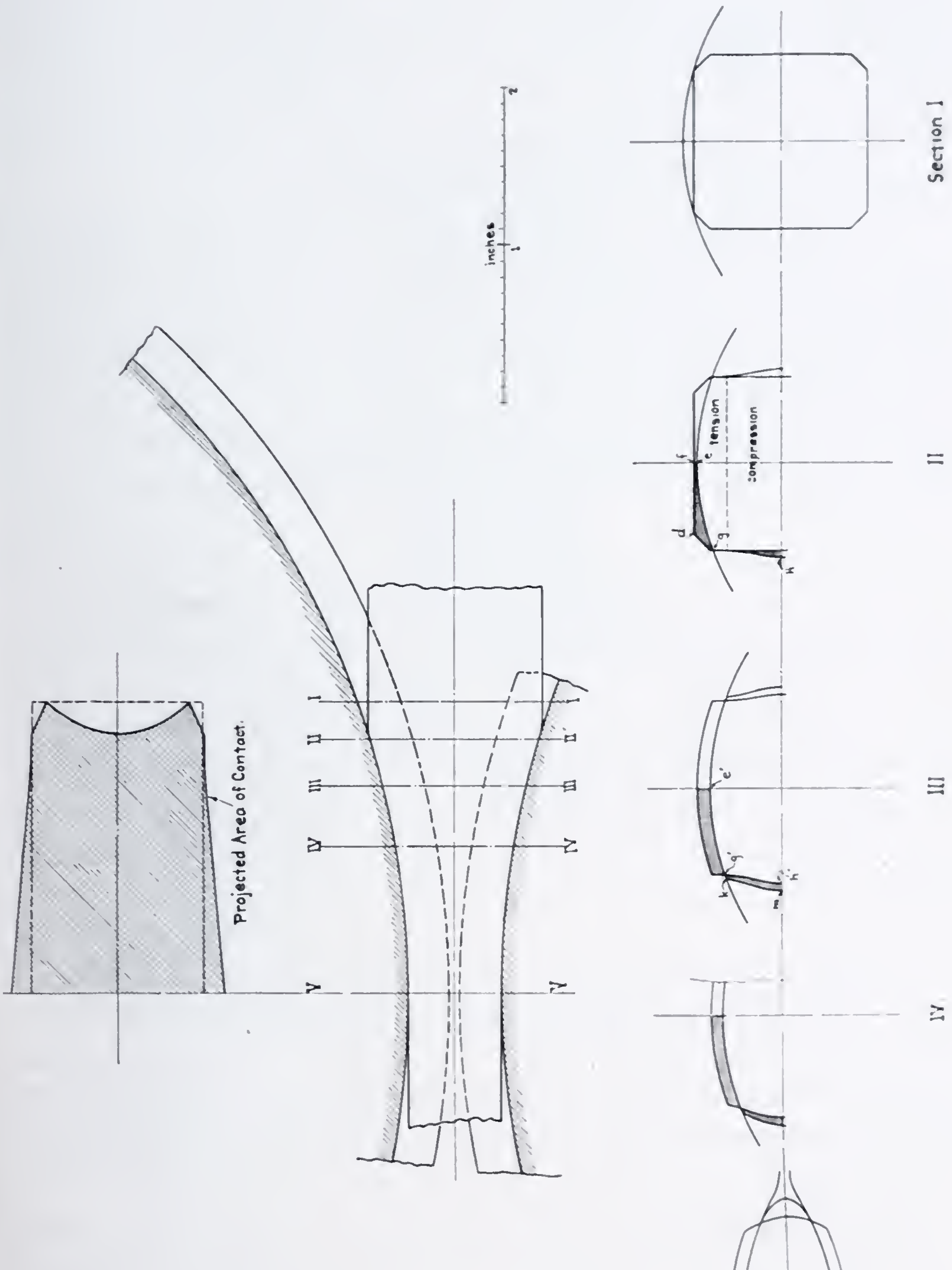

Fig. 17. Method of Analyzing the Deformation of Steel in a Given Pass.

In Fig. 17, I reproduce one of the many illustrations from that series, in order to indicate the method of analysis. Parallel sections were made on the approach side of the rolls; the shape of the groove as it appears in each of the sections was drawn; and deformations were calculated on the basis of probability, using judgment rather than mathematical deductions.

The statement was made in the earlier part of the paper that deformations of the steel were limited by the tensile strength of the steel. At first thought, it may seem absurd that a compression process should produce tension, but even a brief study proves that tension is present in various places. Take, for instance, the simple case of rolling rectangular sections in cylindrical rolls (Fig. 18). A straight line, *1-2*, becomes curved as indicated by *3-4*

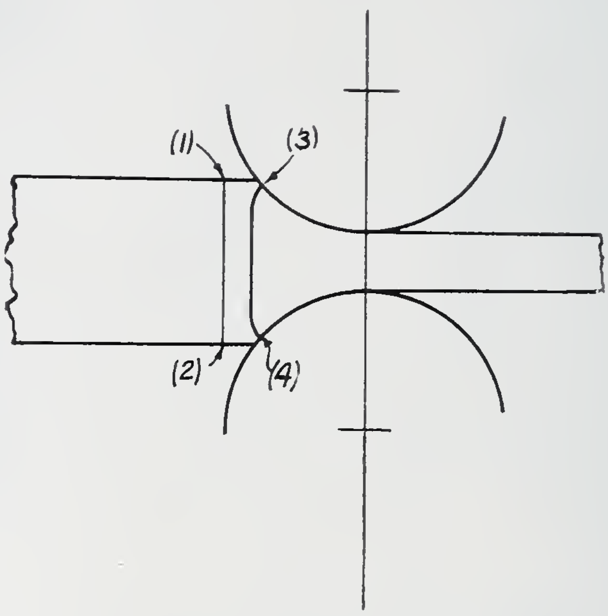

Fig. 18. Diagram Showing Tension in the Outer Layers of Steel Entering a Set of Rolls.

just after the first point of contact with the rolls. The skin of the steel is elongated and subjected to tension while the center is pushed back.

Another manner of producing tension is illustrated in Fig. 19 which represents a bar passing between two rolls. The center part (section lined vertically) is elongated by direct compression. The side parts (section lined horizontally) are taken along by the elongation of the center part, being tied to it by shear forces. At the edges *AA*, the forces amount to practically nothing but tension, and the steel cracks if the elongation exceeds certain limits which depend upon a multitude of factors. This behavior of

material in the rolls is, of course, the reason for the necessity of turning the steel 90 degrees after every few passes. The same reasoning which was used in connection with Fig. 19, applies

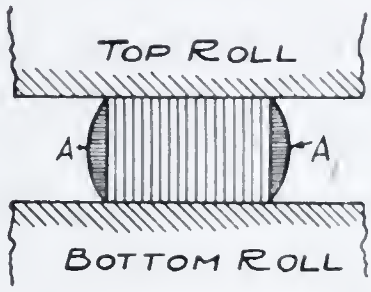

Fig. 19. Deformation Due to Compression and Tension. Heavy Reduction.

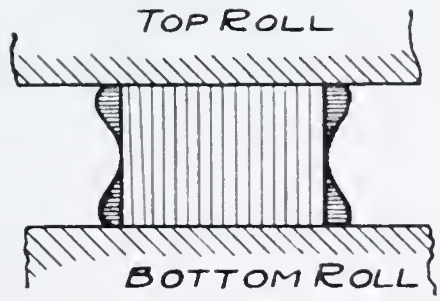

Fig. 20. Deformation Due to Compression and Tension. Light Passes.

likewise to Fig. 20. In this connection it is interesting to note that, if heavy reductions are made, steel is deformed as in Fig. 19. If the passes are light, it assumes the shape of Fig. 20. I have a theory as to why this happens, but am not absolutely certain about its correctness and would like to have some discussion upon this problem.

After a thorough inventory of our present knowledge of the theory of the rolling-mill, we cannot help but realize how much remains to be done in the field of rolling-mill engineering. Some of the officials of various steel companies have vision enough to see the desirability and advisability of lifting rolling-mill engineering from the level of a rule-of-thumb art to the higher plane of a science, but there are others who are self-satisfied and delude themselves into the belief that they know all that is worth knowing in the rolling-mill field.

In concluding this paper, I will ask your pardon for placing the emphasis upon what we do not know rather than upon what we do know. It would be quite possible to amplify the little that we know, but it is so small compared to what we should know that it is hardly worth while. As a possible bright spot in the darkness

of lack of scientific knowledge, there remains the hope that some of our large steel corporations really know more than appears outwardly; but, if they do, their employees give no indication of such knowledge—and of what avail is the knowledge of a very limited circle of officials if the rank and file are kept in ignorance?

Just when this paper was ready, there came to hand the 1919 volume of *Stahl und Eisen,* in which Dr. K. Rummel offers an even more detailed study of the same subject. I quote from his paper:

"The realization of the existence of these difficulties and the large number of variables (even in the simplest case) lead to the conclusion that the influence of the individual variables on the deformation work can be investigated only in a special experimental rolling-mill."

THE BUREAU OF ROLLING-MILL RESEARCH

By W. B. Skinkle*

Prof. Trinks has just given you a paper setting forth the present status of the rolling-mill as a scientific problem, laying stress on those points which still remain unsolved, and on which engineers are badly in need of more data obtained under conditions in which each of the many variables may be controlled with a far greater degree of accuracy than is at present possible.

The inability of engineers to exercise accurate control over these variables makes it advisable to install a special mill, designed for experimental work, and equipped with recording instruments which will enable the observers at all times to determine accurately just what is taking place in all parts of the mill during an experimental run.

The requirements for such a mill might be classed under the following heads:

1. Plenty of power.
2. Ability to reverse the direction of rotation at will.
3. A wide range of speeds.
4. A wide range of types of mills.
5. Ability to roll a wide range of product.
6. Ability to assemble a wide range in sizes of rolls.
7. A set of measuring instruments which will enable the accurate determination of what is going on during the experiment.
8. Equipment so designed that alterations to suit special experiments may be easily made at a comparatively low cost.

In general this might be summed up in the single word, "flexibility."

The Carnegie Institute of Technology will set aside building space of approximately 30 by 135 feet, to house the mill and its auxiliary equipment.

*Director, Bureau of Rolling-Mill Research, Carnegie Institute of Technology, Pittsburgh.

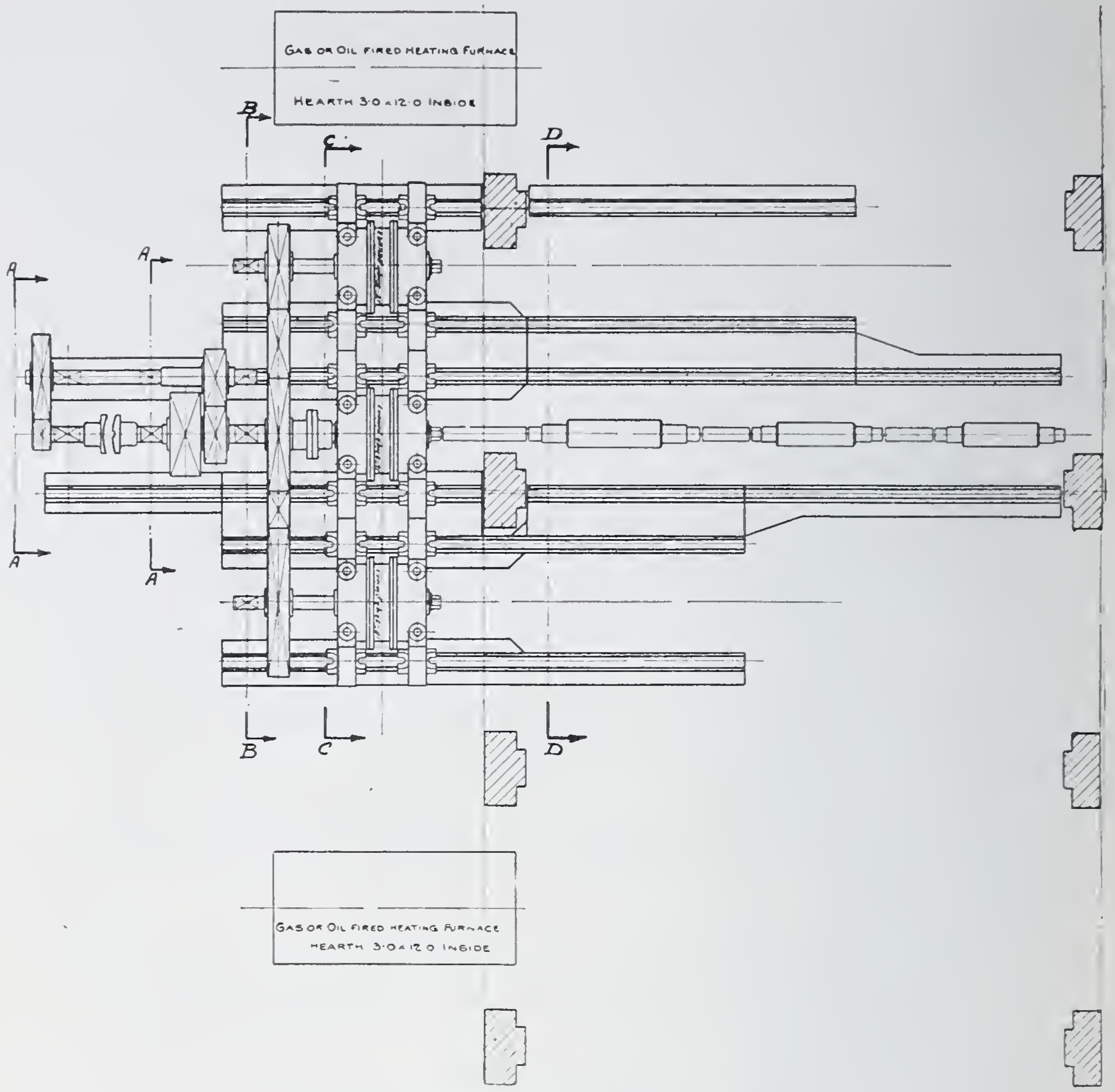

Fig. 1. Diagram of Mill and Drive.

Fig. 1 shows a diagram of this laboratory and the equipment which we contemplate installing. The mill and drive, as will be seen, consist of a motor, suitable gear reduction, three stands of pinion housings, three stands of mill and three lines of shoe-plate. The auxiliary equipment will consist of two stationary heating furnaces, one movable electric furnace, two hot saws and a roll lathe, with roll racks, steel racks, etc.

The source of power supply for driving the mill motor will be obtained from a 500 kilowatt, 230-volt, direct-current Westinghouse generator direct connected to a 30- by 42-inch Mesta uniflow steam-engine. This generator will be withdrawn from the general circuits at the Institute during the operation of the experimental mill and will be placed on the armature circuit of

the mill motor. The fields of both the mill motor and the generator will be excited from the regular 230-volt supply. The generator is to be operated at all times as a shunt-type machine.

The motor will have both series and shunt field windings and will operate either as a compound or a shunt machine depending on the position of the controller in the pulpit. When ready for operation the generator will be running at full speed, the rheostat handle in the pulpit will be in the "off" position, and the generator will have no field current and consequently will generate no power. The mill motor will therefore be stationary. At the first contact point the motor fields will receive the full 230-volt line voltage and have maximum density, while the armature fields will receive only a very light current as the maximum resistance will be in this circuit. A current at very low voltage will therefore be sent to the mill motor, the armature of which will revolve in the strong field at a very low rate of speed. The speed at which the mill motor runs is practically proportional to the impressed voltage and is independent of the load, up to full field on both motor and generator.

The controlling rheostat will have 50 contact points for rotation of the motor in either direction. The first 20 of these points will gradually cut out the resistance in series with the generator field, thereby increasing the voltage of the current generated, with a resulting increase in the speed of the mill motor. At the twentieth point, all resistance has been cut out of the generator field and full voltage is applied to the mill motor, which is now up to its speed of 250 r.p.m. and has its maximum field density. At the twenty-first contact point, slight resistance is cut into the field circuit of the motor, weakening its field and increasing its speed. This is continued for the remaining 29 steps when the speed of the motor has reached the maximum of 750 r.p.m. When operating as a reversing mill, the motor is rapidly brought to rest by regenerative braking. This is accomplished by lowering the voltage of the generator below that corresponding to the speed of the motor and pumping power back into the generator. A large proportion of the decelerating energy is reclaimed by the resulting increase in speed of the generator fly-wheel. Reversing the mill motor will be accomplished by reversing the direction of

the current in the generator field. This avoids the difficulty of handling and reversing the heavy currents in the armature circuit.

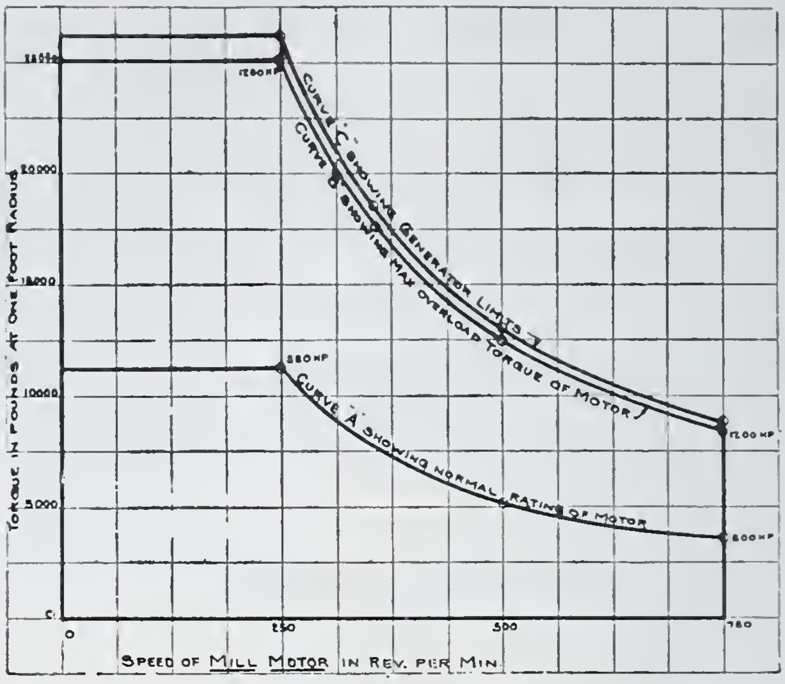

Fig. 2. Torque Speed Curve of Mill Motor.

Fig. 2 shows the torque-speed curves of both motor and generator. Curve *A* is the normal continuous duty curve of the motor. Curve *B* is the maximum torque curve of the motor and curve *C* is the maximum torque curve of the generator.

The motor will be specially designed for rolling-mill service, particular care being taken to insure reliability under the conditions to be met in the severe service of an experimental mill. As already mentioned it will have a speed range from zero to 750 r.p.m. in either direction.

Special attention will be given to the windings of the armature, and to the commutator on account of the severe service due to the sudden large changes in speed, when reversing. The control will be accomplished by means of a hand operated rheostat and will be so interlocked that the motor will always have a full field when starting. Between the generator and the motor a manually operated, high-capacity circuit-breaker will protect the generator from abusive overload. Several sets of push-buttons will be located at various points about the mill and pulpit, to trip this circuit-breaker in case of emergency.

In addition to the hand operated rheostat for controlling the motor, the pulpit will contain a switchboard on which will be mounted an indicating ammeter and voltmeter as well as the necessary signal lights to indicate the position of the main circuit-breaker.

For observing the power conditions when the mill is operating the following instruments will be used:

One indicating, direct-current voltmeter (zero center).
One indicating, direct-current ammeter (zero center).
One indicating speed meter for the mill motor (zero center).
One indicating speed meter for the generator (single deflection).
One graphic, direct-current voltmeter (zero center).
One graphic, direct-current ammeter (zero center).
One graphic speed meter for the motor (zero center).
One graphic speed meter for the generator (single deflection).
One magneto, connected to the motor shaft.
One magneto, connected to the generator shaft.

The graphic instruments will have one chronographic pen on each margin—one to be connected to a seconds pendulum, and the other for recording the exact revolutions of the mill. This set of pens will enable all recording diagrams to be connected together when they are plotted on the final report charts.

The recording instruments will all be of the switchboard type. As it is the intention of the Bureau to run repeated tests it would be neither convenient nor good engineering to use portable test instruments for this work.

Fig. 3–5 show three possible assemblies of the gear reductions between motor and mill. In Fig. 3 the power is transmitted from the armature shaft through the motor pinion and gear to the jack-shaft with a reduction of 3.1 to 1. From the jack-shaft through its pinion and the main driving gear to the main shaft we secure a second reduction of 3 to 1, making a total reduction of 9.3 to 1 between motor and mill. You will note a second gear on the main driving shaft which is entirely idle. This is used in other combinations.

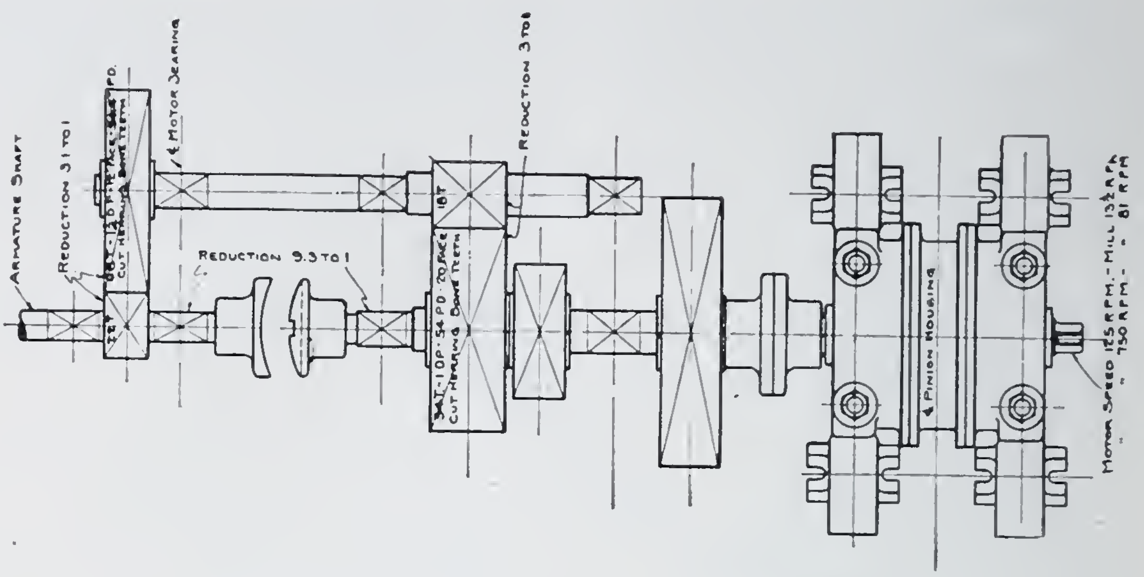

Fig. 3. Gear Diagram No. 1.

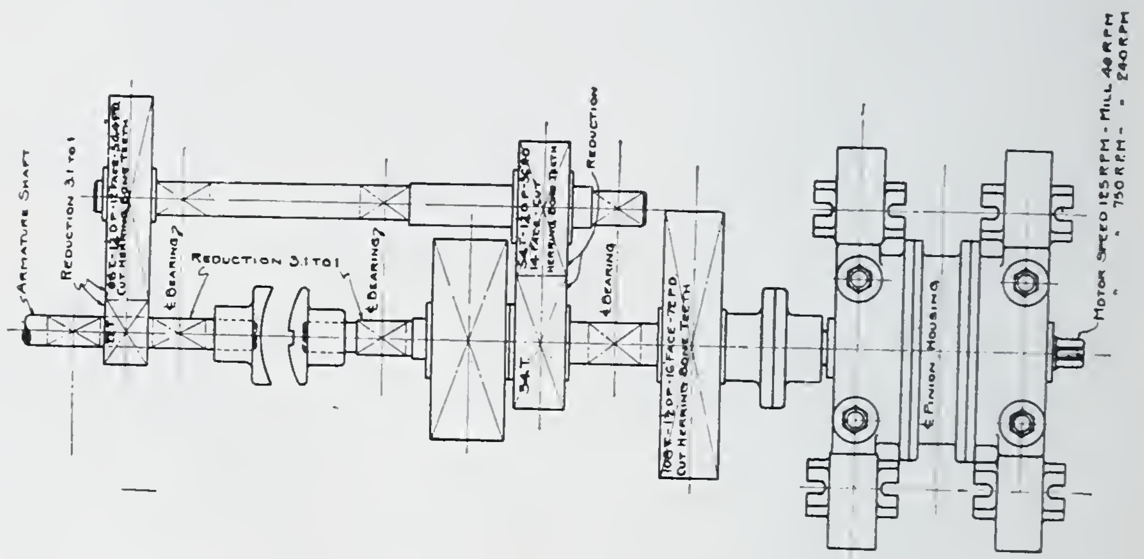

Fig. 4. Gear Diagram No. 2.

With the arrangement just described it will be possible to deliver to the mill a maximum overload torque of 230,000 pound feet. The speed range as shown will be from 13.5 to 81 r.p.m. at the mill.

Fig. 4 shows a second combination of gearing. In this arrangement the main driving pinion has been changed, and the second set of gears is now a 1 to 1 ratio, giving a total reduction between motor and mill of 3.1 to 1. This will give a maximum overload torque at the mill of 78,000 pound feet. The speed range of the mill will be from 40 to 240 r.p.m.

It is expected that about 90 per cent. of our work will be

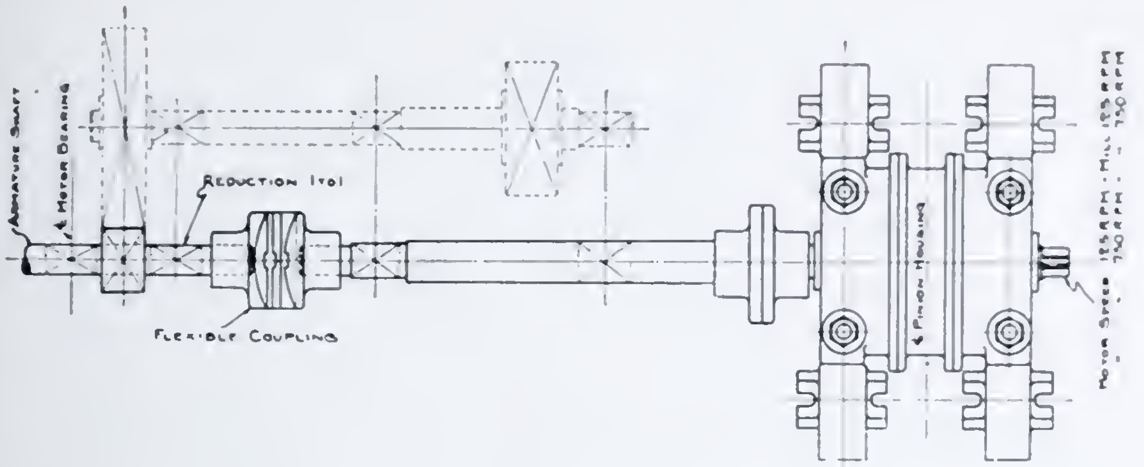

Fig. 5. Gear Diagram No. 3.

done with this combination of gears, as the 40 r.p.m. is close to the sheet-mill speed, and 240 r.p.m. is a good bar-mill speed.

When a mill speed greater than 240 r.p.m. is desired, the jack-shaft will be lifted out of its bearings and the missing parts of the flexible coupling slipped into place. The mill will then be direct connected as shown in Fig. 5. In this drawing the jack-shaft is indicated in dotted lines and the gears have been stripped from the main shaft. At 240 r.p.m. the largest gear will have a rim speed of nearly 5000 feet per minute. This rim speed would rise to nearly 15,000 feet per minute at 750 r.p.m. It was therefore thought advisable to replace this main shaft with a second shaft or at least to strip the gears from the main shaft before attempting to run at the high speeds. With this arrangement the motor will deliver a maximum torque of 25,000 pound feet to the mill.

Referring back to Fig. 1, we note that the power in the main shaft may be split three ways. One part may be sent directly into the middle, or 16-inch, pinion housing; a second part may be transmitted through the large driving gear to the 18-inch pinion housing; and the third portion in the opposite direction to the 12-inch pinion housing. The intermediate gears are inserted to give the correct direction of rotation to the first and third pinions. These will all be cut gears of the highest grade herringbone type.

Taking up the construction more in detail you will note that the armature shaft of the motor has been extended to pass through an outboard bearing and carry half of a flexible coupling on its end.

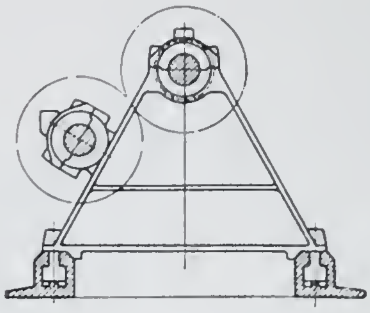

Fig. 6. Section Through Driving Shafts, on Line *AA* of Fig. 1.

Fig. 6 is a section on the line *AA* of Fig. 1 and shows this bearing frame in side elevation. The frame rests on an extension of the shoe-plates and is rigidly held in place by lugs and bolts. The bearing for the jack-shaft is cast to the side of this frame.

This section is duplicated for the middle bearing frame of the jack-shaft, the only difference being in the diameter of the main shaft bearing.

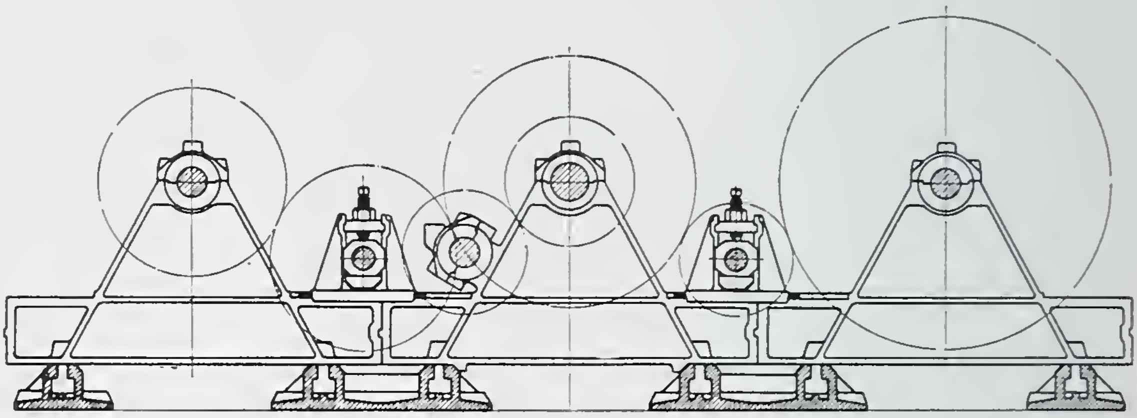

Fig. 7. Elevation of Bearings for Spur-Gear Drive, on Line *BB* of Fig. 1.

Fig. 7 is a section on the line *BB* of Fig. 1 and shows a side elevation of the bearing frames for the outboard bearings of the continuous mill drive.

These frames are very similar to the one just described, except for the extensions carrying the bearing for the idle gears. The middle frame is held rigidly in place on the shoe-plates by lugs and bolts. The two outer frames are connected to the middle frame by tongue-and-groove joints with bolts. The lugs at the shoe-plates are omitted on the two outer frames to allow the castings to be drawn firmly together by the connecting bolts.

The outline of the spur-gear drive is indicated by dotted lines. A 25 per cent. reduction is shown at each pass.

The bearings for the idle gears are adjustable both in a horizontal and vertical direction and are bolted and keyed to their

bases. Should any co-operator wish to experiment on continuous mills and duplicate his mill conditions exactly, it is only necessary to change one gear between any two stands. This construction is therefore less expensive to change than the usual construction of bevel-gear drive for continuous mills, as both gears of every set would have to be changed if any change at all were made in this last type.

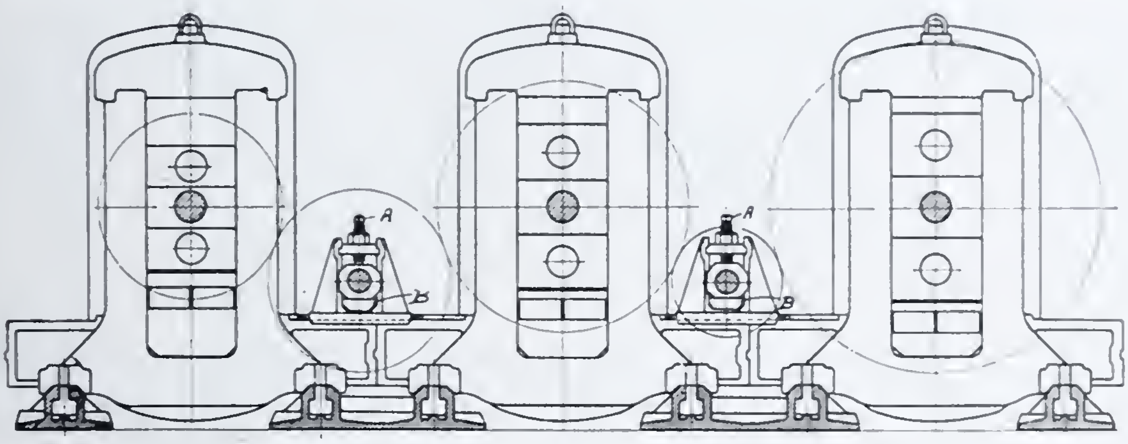

Fig. 8. Side Elevation of Pinion Housings, on Line *CC* of Fig. 1.

Fig. 8 is a section taken on the line *CC* of Fig. 1 and shows a side elevation of the pinion housings. These housings have extensions for carrying the bearings of the idle gears, which are exact duplicates of those cast on the bearing frames.

If the mill is to be used as a straight, hand-fed, three-high bar mill, the first and third pinion housings will not be used.

To disconnect these housings, the bolts, *A,* are loosened and the fillers, *B,* removed, allowing the idle gears to drop down out of mesh with the driving gears. The gears may be easily raised and fillers replaced in a few minutes when the outer pinion housings are to be put into service.

All bearings throughout the entire mill and drive are to be so designed that babbitt, bronze, rollers, or ball-bearings may be used in them. We will thus be able to secure comparative data on power requirements for all classes of these bearings. We have two of the leading ball- and roller-bearing manufacturers signed as members and taking a very active interest in the work.

Fig. 9 is a section taken on the line *DD* of Fig. 1 and shows a side elevation of the three stands of mill assembled as a continuous mill. The top rolls have been abandoned and only the lower rolls kept in service.

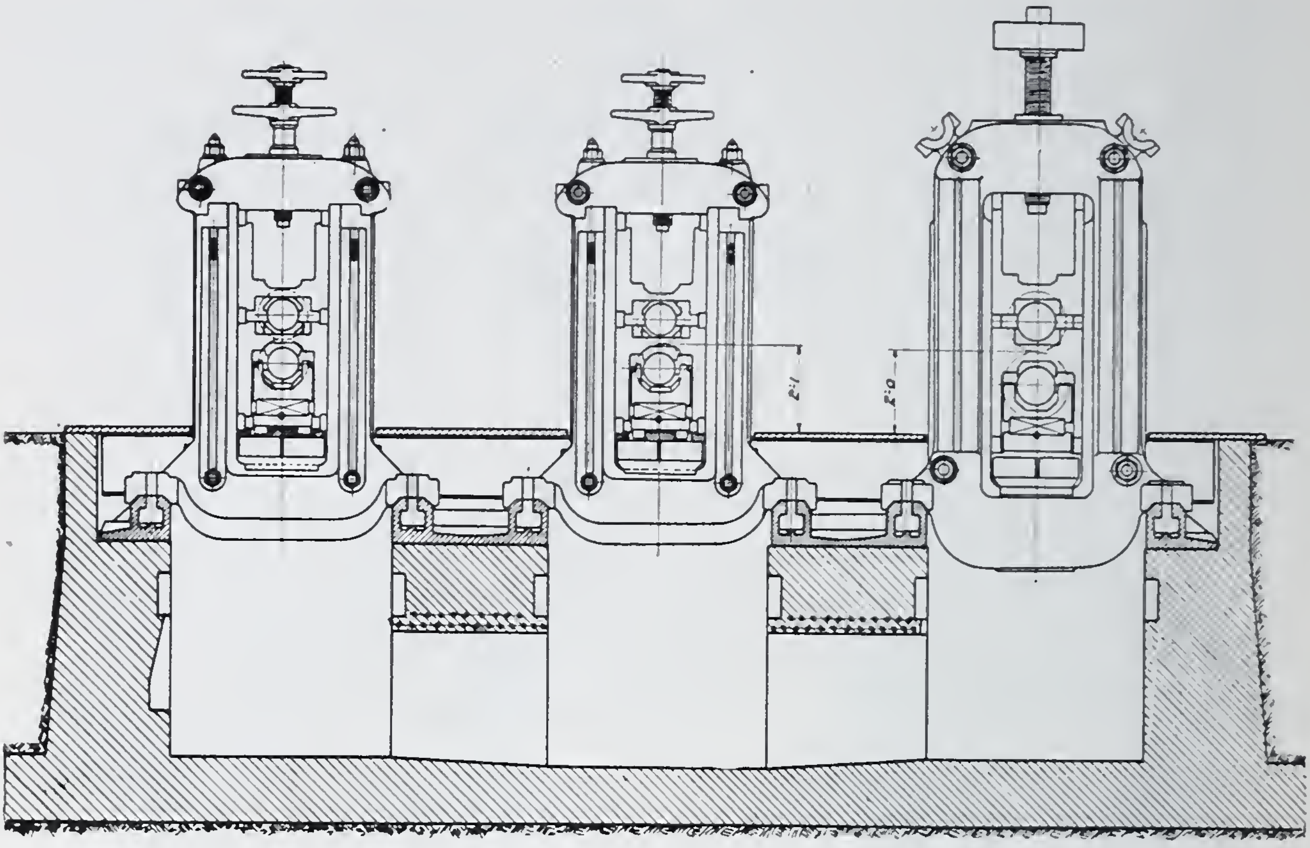

Fig. 9. Side Elevation of Continuous Mill, on Line *DD* of Fig. 1.

The author believes that three stands are sufficient to investigate the flow of metal in continuous mills. Take, for example, the middle stand. It has three functions to perform: First, it must take care of all the metal delivered to it by the first stand; second, it must make the proper change in the shape of this metal; third, it must deliver the metal to the third stand at exactly the proper rate of speed.

Fig. 10 is a plan view of the assembly of this continuous mill. The mill housings are of two designs. One is a large closed-top housing and the other two are smaller open-top housings.

I would call your attention to the fact that, through quite a large range of types of mills, the housings are quite similar, the chief differences being a lug here or a core there. In my design of these housings I have endeavored, as far as possible, to put all the lugs and all the cores for all the mills onto these housings. To change the type of mill it then becomes only a matter of fillings for the windows. To permit the interchange of fillings, the windows in all housings are made duplicates as nearly as is possible. The housings have machined surfaces and grooves on all sides to facilitate special attachments.

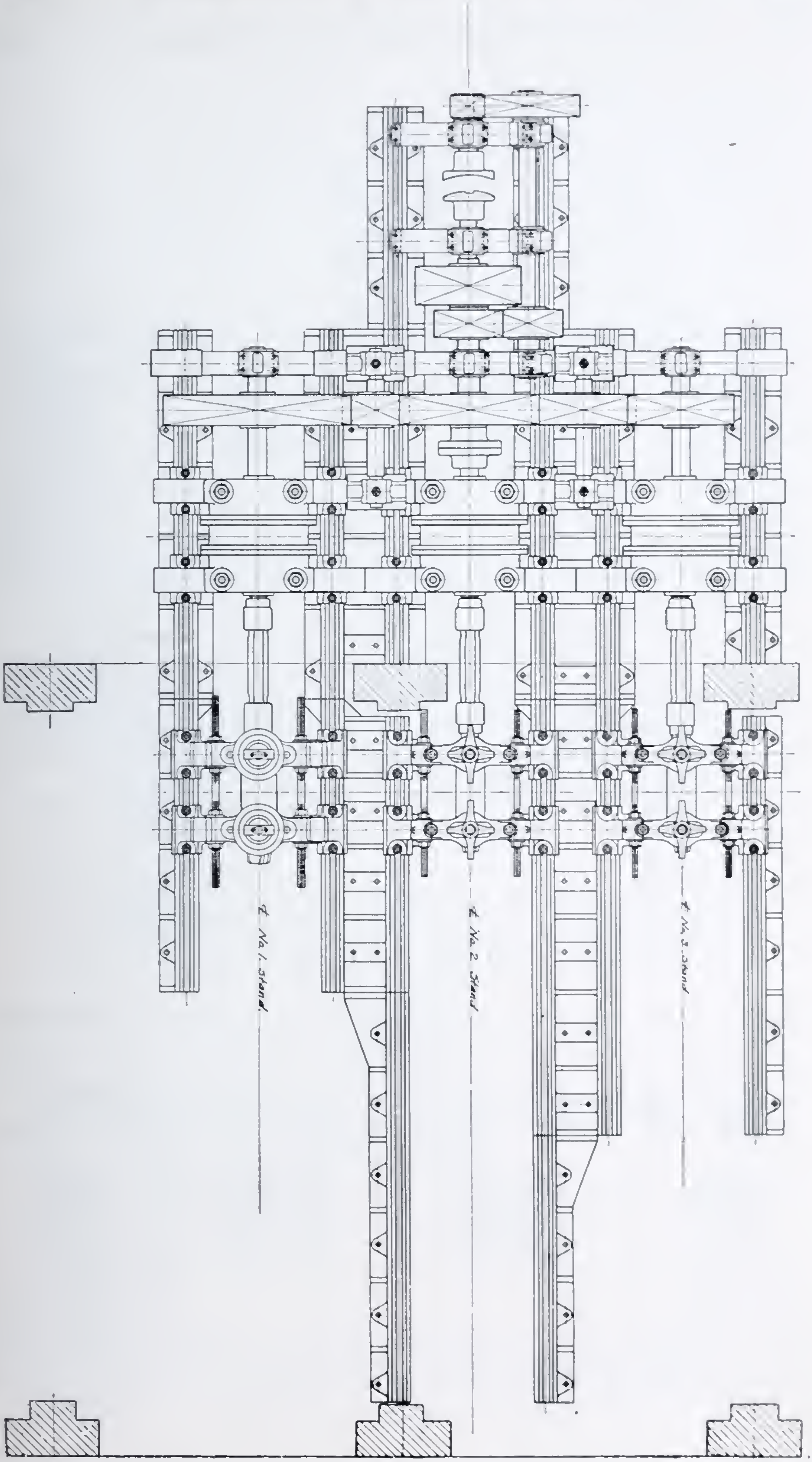

Fig. 10. Plan of Continuous Mill and Drive.

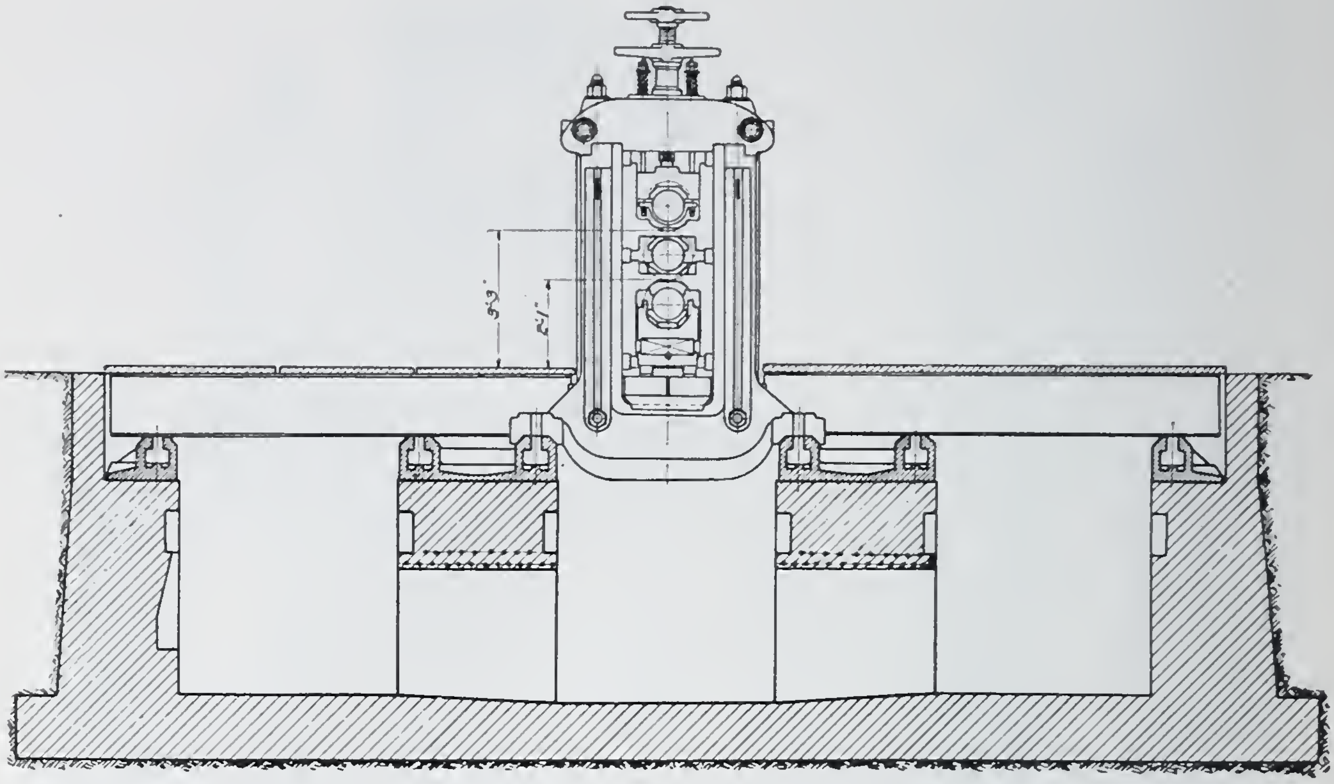

Fig. 11. Side Elevation of 14-Inch, Open-Top, Roll Housing.

Fig. 11 is a side elevation of the small housing assembled on the shoe-plates as a three-high bar mill. The shoe-plates are dropped below the floor just far enough to allow an 18-inch I-beam to be placed on them and bring their tops to the floor level. Cast-iron floor plates are laid on top of these I-beams in the manner shown.

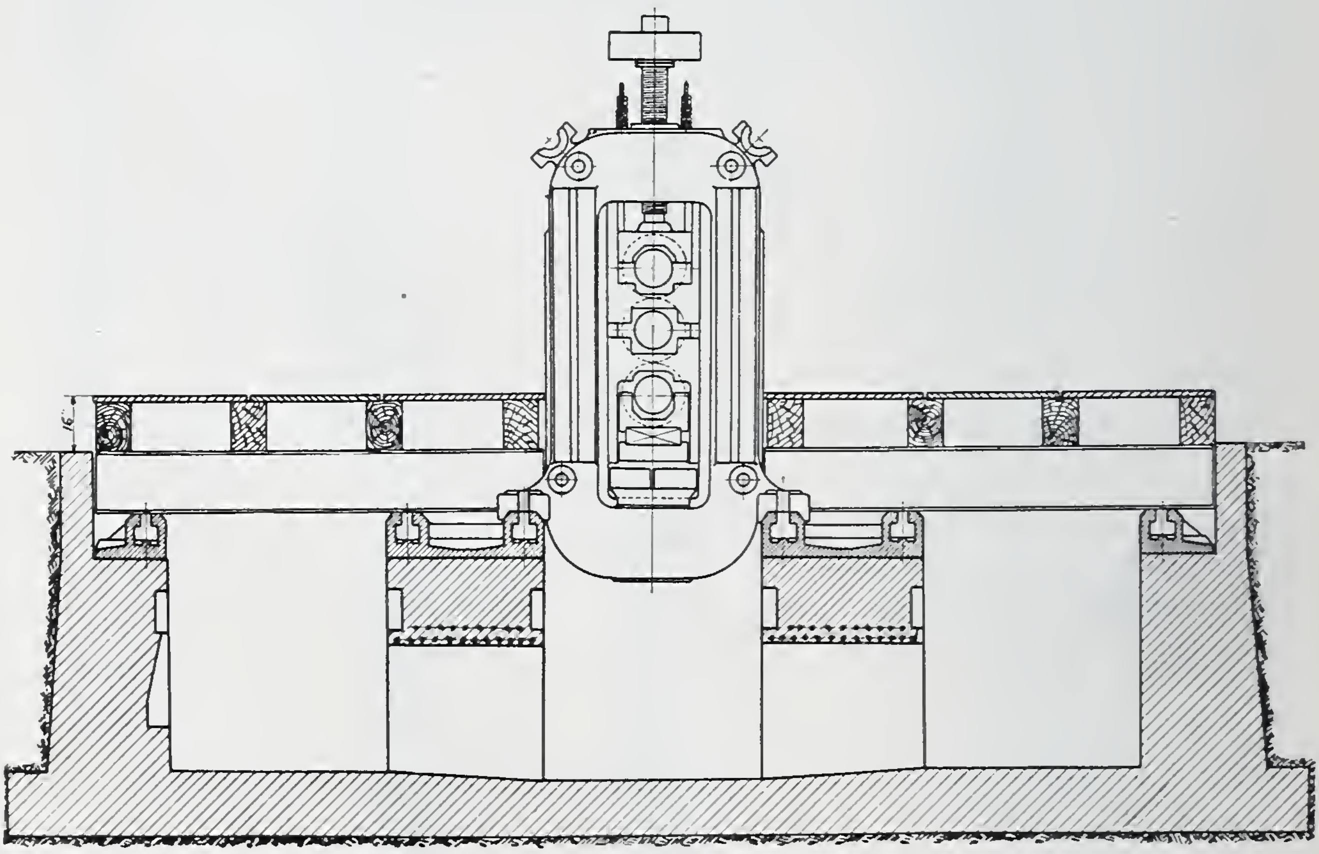

Fig. 12. Side Elevation of 18-Inch, Closed-Top, Roll Housing.

Fig. 12 shows a side elevation of the large housing assembled as an 18-inch three-high bar mill. When rolls of this size are used, the sections rolled may get fairly heavy and be difficult to lift high enough to return through the top rolls. In order to cut down this lift as much as possible, a number of 10- by 16-inch timbers are laid across the 18-inch I-beams, and the floor plates arranged as shown. This brings the floor level as high as the guides for the bottom rolls will permit, and cuts down the lift necessary to return the billet through the top rolls.

In case the bloom to be rolled is too heavy to be handled by workmen, the entire floor system may be removed and two small lifting tables of light design substituted, as shown in Fig. 13. In

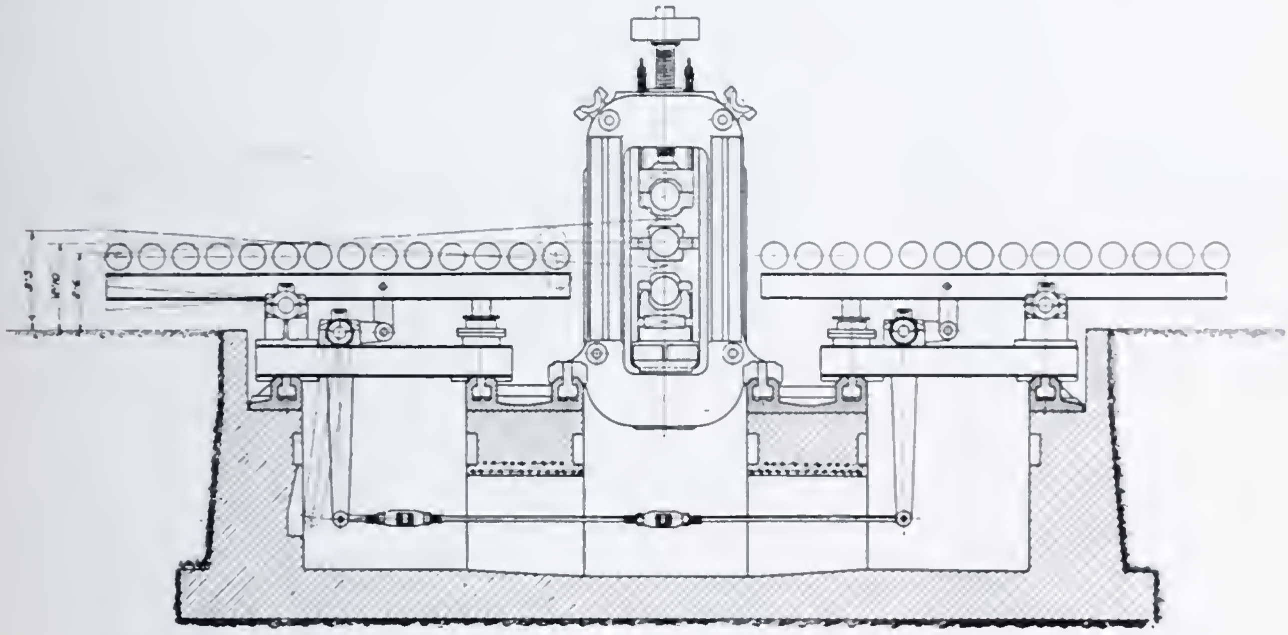

Fig. 13. Lifting Tables Applied to 18-Inch, Three-High Mill.

this construction the outer lines of shoe-plates are used as foundations for supporting the small structural girders that carry the fulcrum bearings and synchronizing mechanism. The lifting cylinders for the tables have feet cast on the bottom head. These feet fit the inner shoe-plate and are bolted to it.

This table will have one additional roller added to the mill end when it is used in connection with a three-high plate mill.

Should this housing be assembled as a two-high blooming or plate mill of the reversing type, the fulcrum bearings and synchronizing mechanism may be replaced by small beams of the proper height laid across the girders. The tables will then become the ordinary type of stationary front and back mill tables.

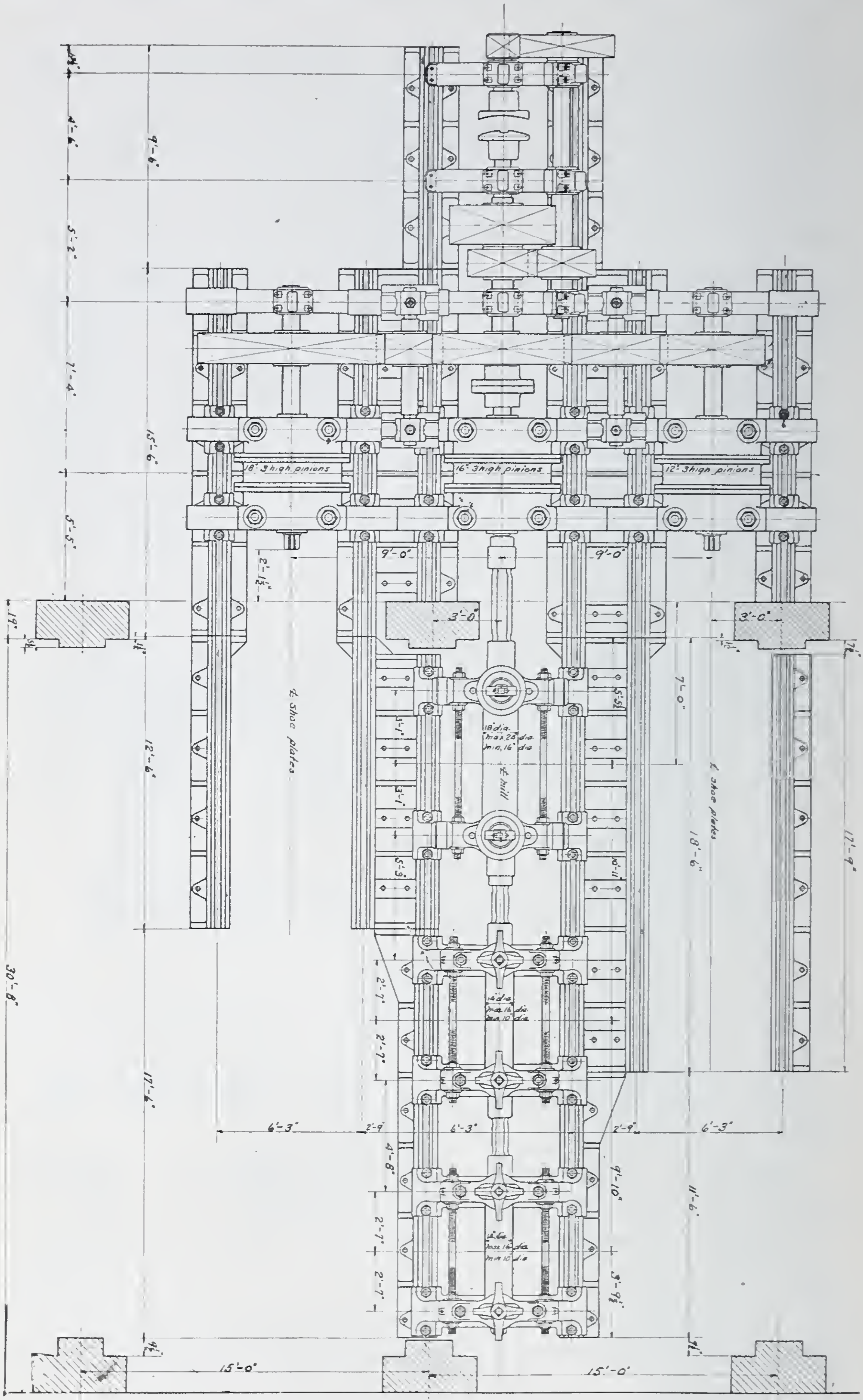

Fig. 14. Plan of Bar Mill and Drive.

Fig. 14 shows a plan view of the mill housings assembled as three stands of three-high, hand-fed bar mill.

Fig. 15 shows a cross-section through the mill when assembled on the middle line of shoe-plates, and used as a three-high bar mill. This assembly shows 16-inch mill pinions driving the first stand of 18-inch, three-high mill and the second and third stands of 16-inch, three-high mill. There is a slight lead on the spindles to and from the 18-inch stand. All pods on both roll necks and spindles are made of the vibrating type to permit as much of this lead as possible without interfering with the operation of the mill.

In extreme cases, say for example an 18-inch roughing and a 10-inch finishing mill, this spindle lead between stands would be too great and it will be necessary to assemble them as shown in Fig. 16. In this assembly the 18-inch rolls are connected to the 18-inch pinions and the 10-inch rolls are connected to 12-inch pinions. There is room between the stands to roll a bar 12 feet long, which should be enough for experimental work.

Before dealing in greater detail with the assemblies of the various types of mills, I wish to describe the devices by means of which we expect to locate and measure the various losses of power throughout the mill.

Fig. 17 shows an exaggerated diagram of a pair of rolls, the lower neck resting in its bearing and supported on two hydraulic support cylinders marked No. 1 and No. 2.

When a bloom is being rolled it will exert a separating force, *F*, tending to open these rolls. A portion of this force, *F*, will be transmitted to each roll-neck. The exact amount of this force will depend on the location of the pass along the body of the roll and can be easily figured by the principles of beam reactions. This force transmitted to one roll neck will be designated as *P*. Under static conditions, this force would be applied as shown by full lines in Fig. 17. Such an application would cause one-half the load as indicated by the arrow, *A*, to be carried by each cylinder.

When rotation starts, contact moves to some other point as indicated by the dotted arrow, *B*. The lower roll carrier has a tendency to assume the position as shown by dotted lines using the roller, *C*, as a fulcrum point, the roller, *D*, lifting off its seat and giving only the very low resistance of rolling friction.

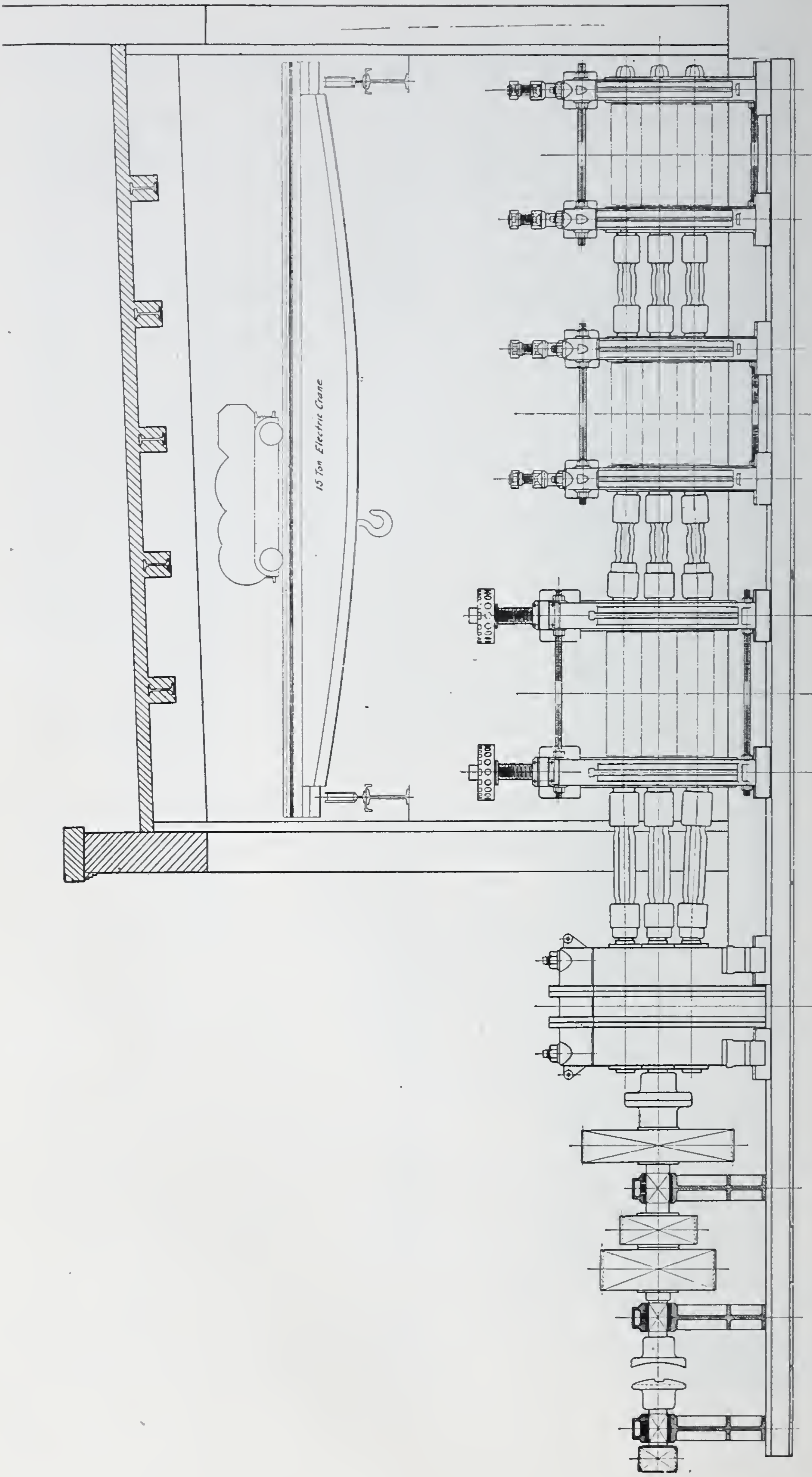

Fig. 15. Cross Section of Bar Mill and Drive.

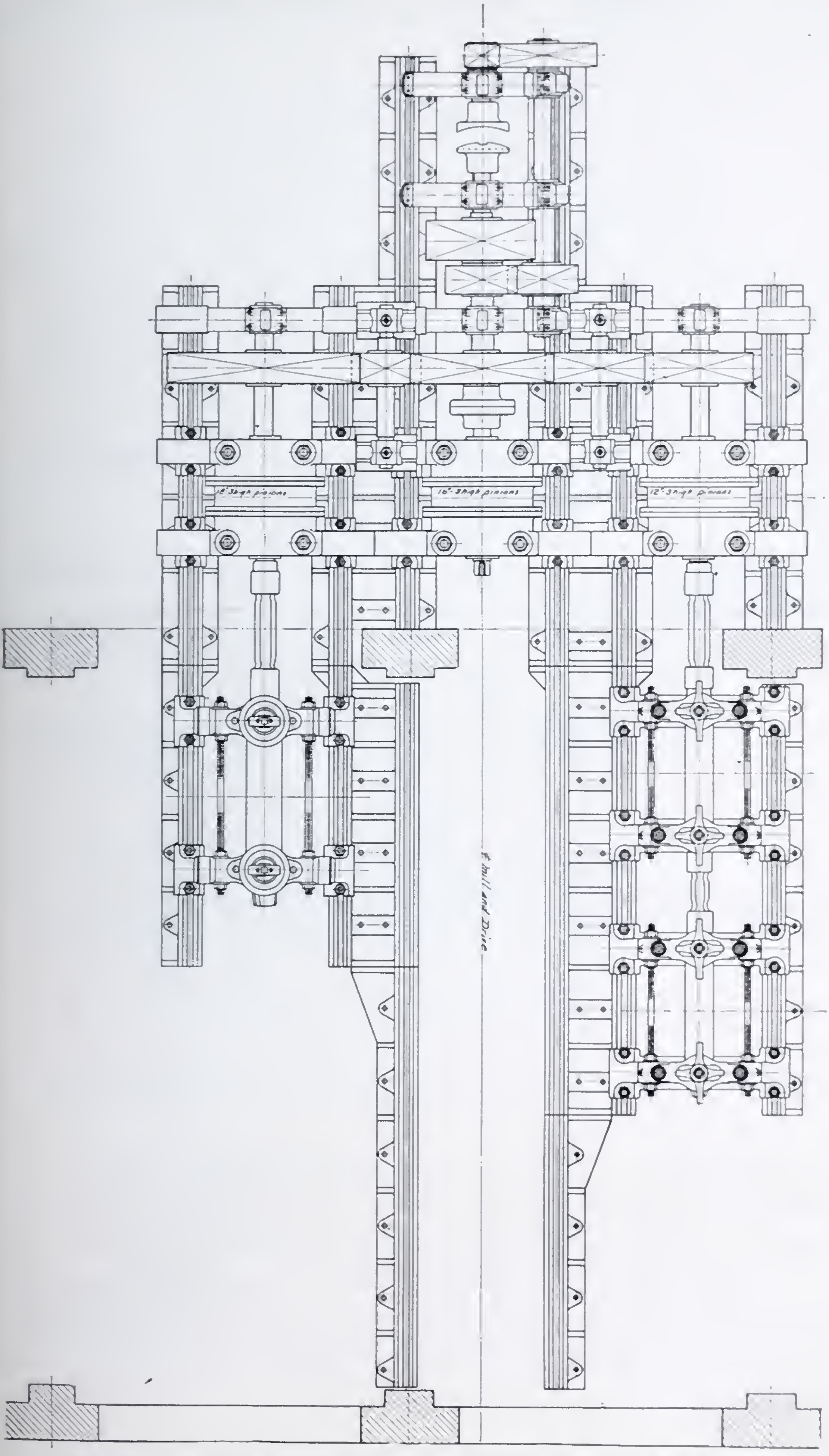

Fig. 16. Plan of Roughing and Finishing Stands, with Drive.

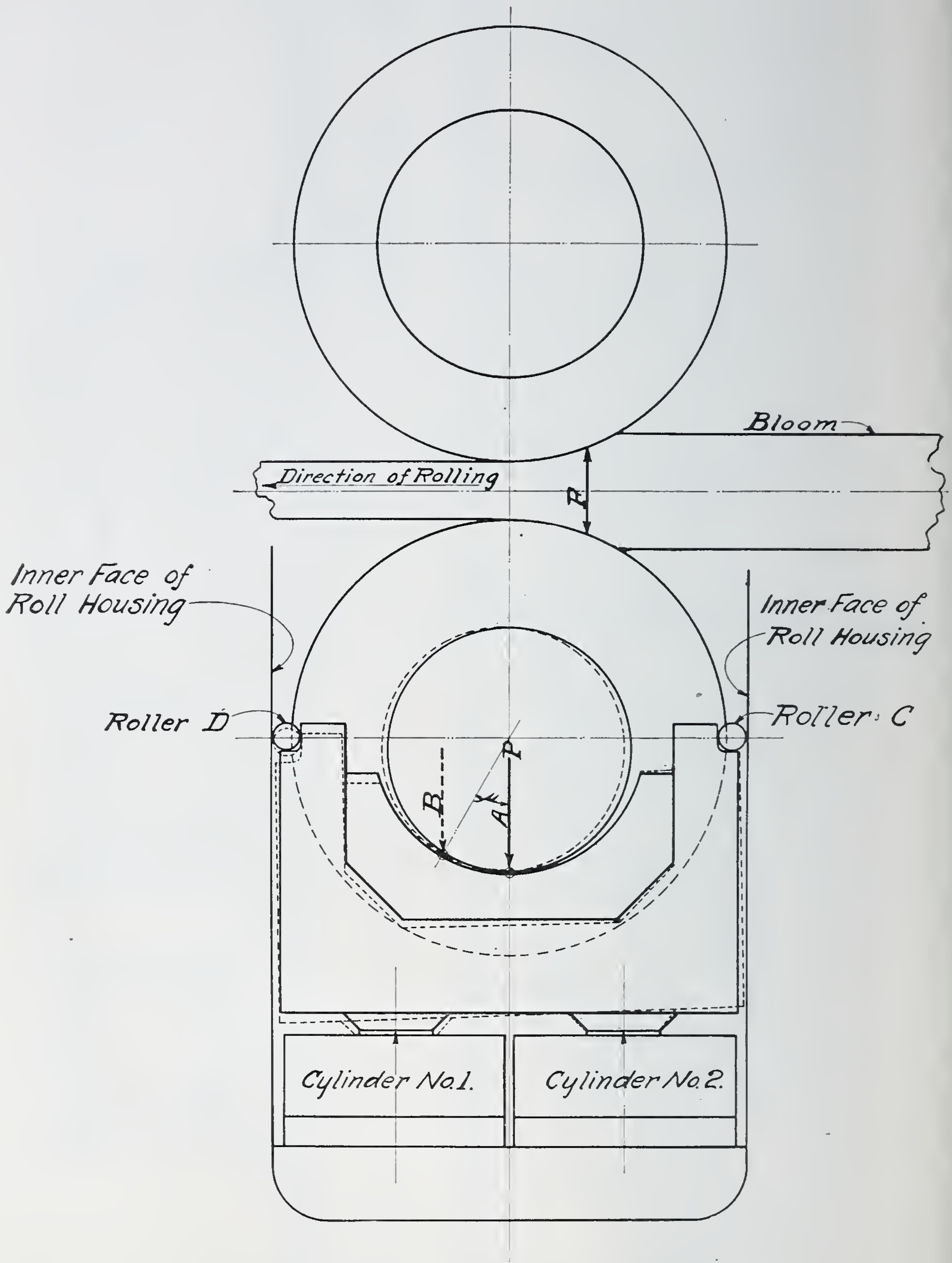

Fig. 17. Diagram of Hydraulic Support Cylinders.

When the contact between neck and bearing has moved to a point where it slides back as rapidly as it tends to climb, the angle of sliding friction has been reached and the system again comes to equilibrium.

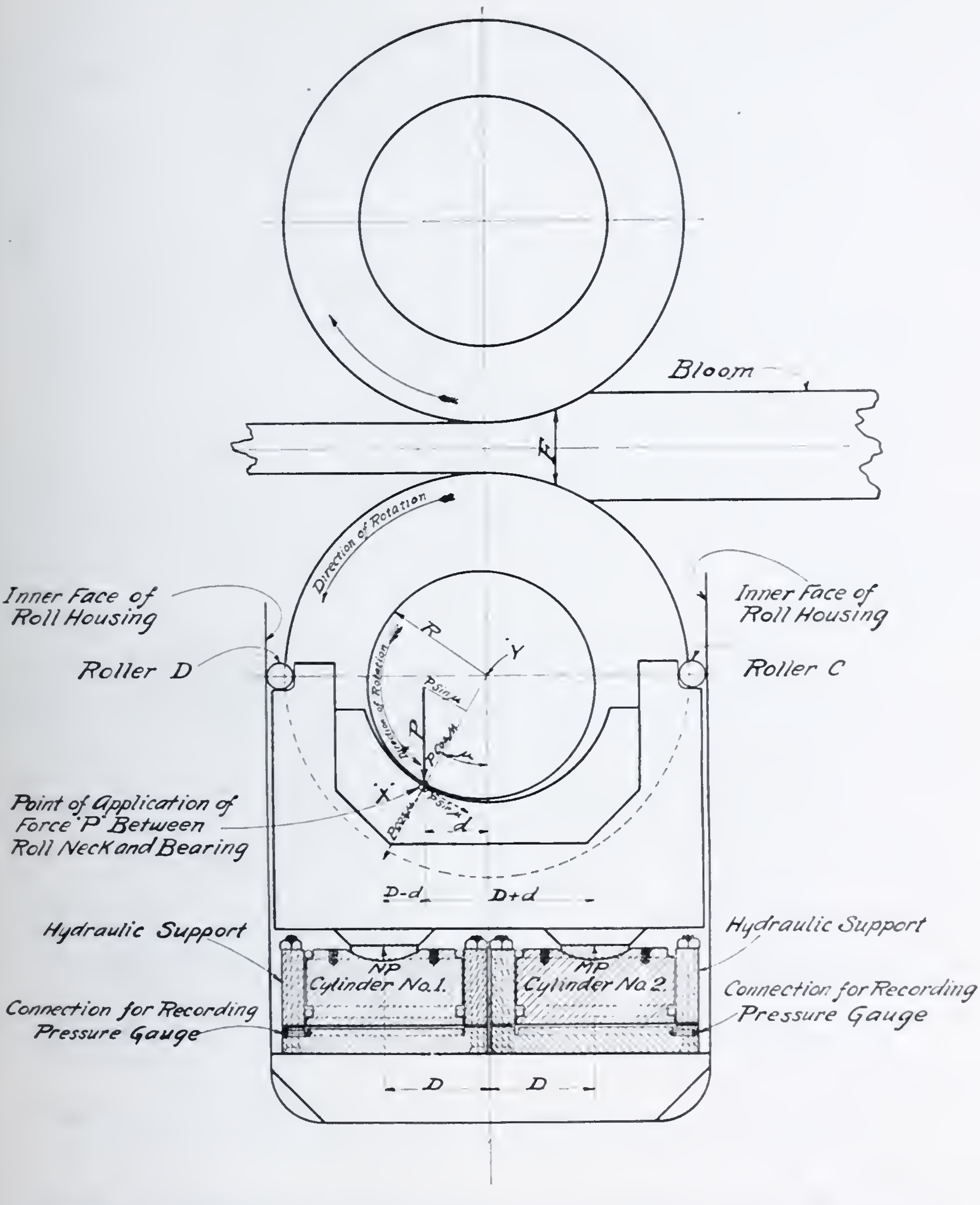

Fig. 18. Analysis of Forces Acting on Hydraulic Support Cylinders.

These conditions are analyzed in Fig. 18. Examination of this figure shows that the vertical force, P, applied at the point, X, may be resolved into its normal force ($P \cos \mu$) and a tangential force ($P \sin \mu$). The diagram shows the downward force, P, resisted by the two upward forces, NP and MP, of the hydraulic support cylinders, where M and N are some fractions, one greater and one less than ½.

Taking moments about the point X, we have
$+ N P (D - d) - M P (D + d) = 0$, which expands into
$$N P D - N P d - M P D - M P d = 0. \qquad (1)$$

Taking moments about Y, the center of the roll neck, we have
$$- P d + N P D - M P D = 0. \qquad (2)$$

Subtracting equation (2) from equation (1) we have
$$P d - N P d - M P d = 0.$$

Canceling $P d$ and rearranging, we have $N + M = 1$.

This shows that for each increase over one-half the load, P, that is put on cylinder No. 1 there will be a corresponding decrease in the load on cylinder No. 2, and that the sum of the loads $N P + M P$ must equal P.

The force P, applied at X, may be resolved into its two components and, if moments are then taken about Y, the equation becomes:

$P \sin \mu R = (N P - M P) D$, which will transpose into
$$\sin \mu = \frac{(N P - M P) D}{(N P + M P) R}. \qquad (3)$$
We have thus arrived at the value of the angle of which the tangent is equal to the coefficient of friction.

The work lost per revolution of the rolls may be figured in two ways. First:

Work lost = (normal pressure) (coefficient of friction) (distance moved).

In this case, letting W = work lost per revolution, we have,
$W = (P \cos \mu) (\tan \mu) (2 \pi R)$. But $\cos \mu \tan \mu = \sin \mu$. The equation may therefore be written,
$$W = P \sin \mu \, 2 \pi R,$$
$$\text{or } W = (N P + M P) \sin \mu \, 2 \pi R. \qquad (4)$$

If we consider the two cylinders as a Prony brake, the equation for work lost per revolution becomes
$$W = (N P - M P) \, 2 \pi D. \qquad (5)$$

It is interesting to note that placing equation (4) equal to equation (5) we have

$$(N\ P + M\ P) \sin \mu\ 2\ \pi\ R = (N\ P - M\ P)\ 2\ \pi\ D.$$

Canceling $2\ \pi$ and rearranging, this equation becomes

$$\sin \mu = \frac{(N\ P - M\ P)\ D}{(N\ P + M\ P)\ R},$$ which is the exact form of equation (3).

The support cylinders are shown in Fig. 19.

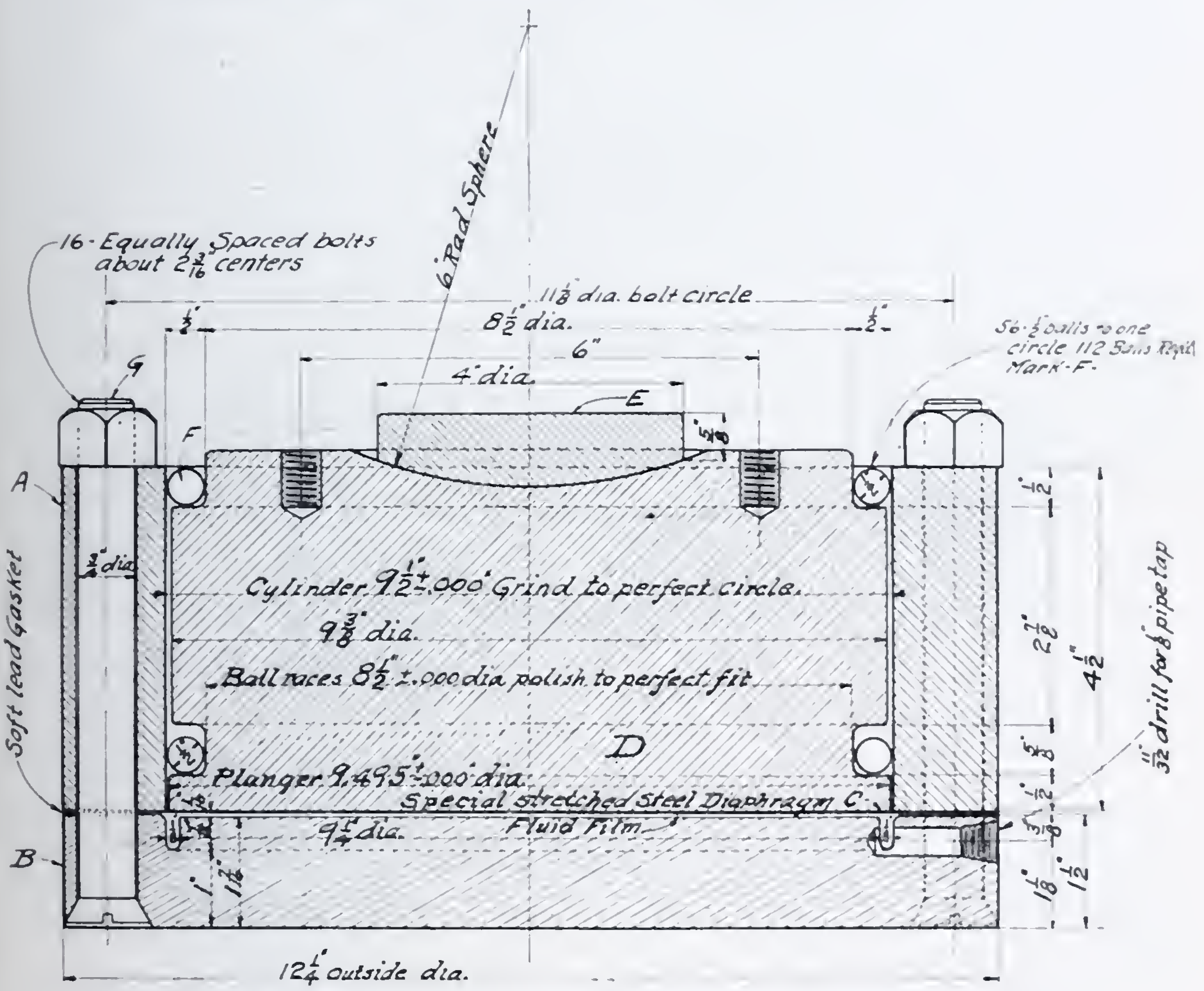

Fig. 19. Section Through Hydraulic Support Cylinders.

The essential parts of these cylinders are an upper or guide cylinder, *A*, with a base, *B*, which base is really the cylinder proper; it being recessed on its upper face to permit a very thin film of fluid to receive the pressure of the plunger, *D*. Interposed between the fluid and the plunger is a metal diaphragm, *C*, which completely traps the liquid in the cylinder. The plunger is held away from the walls of the guide cylinder by means of two rings of balls. These balls are fitted very accurately to prevent the plunger from tilting and thus reducing its friction to that of rolling contact. The fluid film may be water, oil, glycerine,

or mercury. The United States Bureau of Standards has recommended either a light machine oil or a mixture of alcohol and glycerine. Water is compressible 1 volume in 300,000, per pound pressure per square inch, while mercury has a compression ratio of 1 to 4,700,000.

Mr. A. H. Emery of Glenbrook, Conn., is the inventor of this type of cylinder which he used in the 2,000,000-pound testing machine now installed at the laboratory of the United States Bureau of Standards. Calibration of these cylinders records a total pressure of 999,817 pounds recorded on the cylinders for an actual load of 1,000,000 pounds on the specimen—an error of 183 pounds in 1,000,000, or an error of less than 0.02 of one per cent.

In the German government laboratory for testing materials, Dr. A. Martens did a great deal of work with cylinders of this type for recording both large and small loads, and strongly recommends it as the most sensitive type of recording mechanism for loads of almost any magnitude or any suddenness of application. The credit for the arrangement of two of these cylinders in such a manner as to form a Prony brake and record the friction losses on roll necks should go to Prof. W. Trinks.

Fig. 20 shows these cylinders and the details of their application to a three-high bar mill. Note that the lower roll has a wedge adjustment which permits a slight movement of the roll up or down without in any way interfering with the action of the support cylinders.

Another point to be considered in this connection is the fact that the chock or thrust plates, *1*, on the inside of the housing would offer a serious resistance to the turning tendency of the lower roll bearing if the thrust bolts, *3*, which draw the neck brasses against the shoulder of the rolls, were of the usual construction. To avoid this difficulty, the holes for these bolts are drilled large, and both ends of the bolt are made with ball joints. This construction will permit the chocks to remain stationary while the bearing is free to transmit all its turning tendency to the support cylinders.

Fig. 21 shows this construction clearly. These cylinders will be applied to all roll and pinion housings throughout the mill.

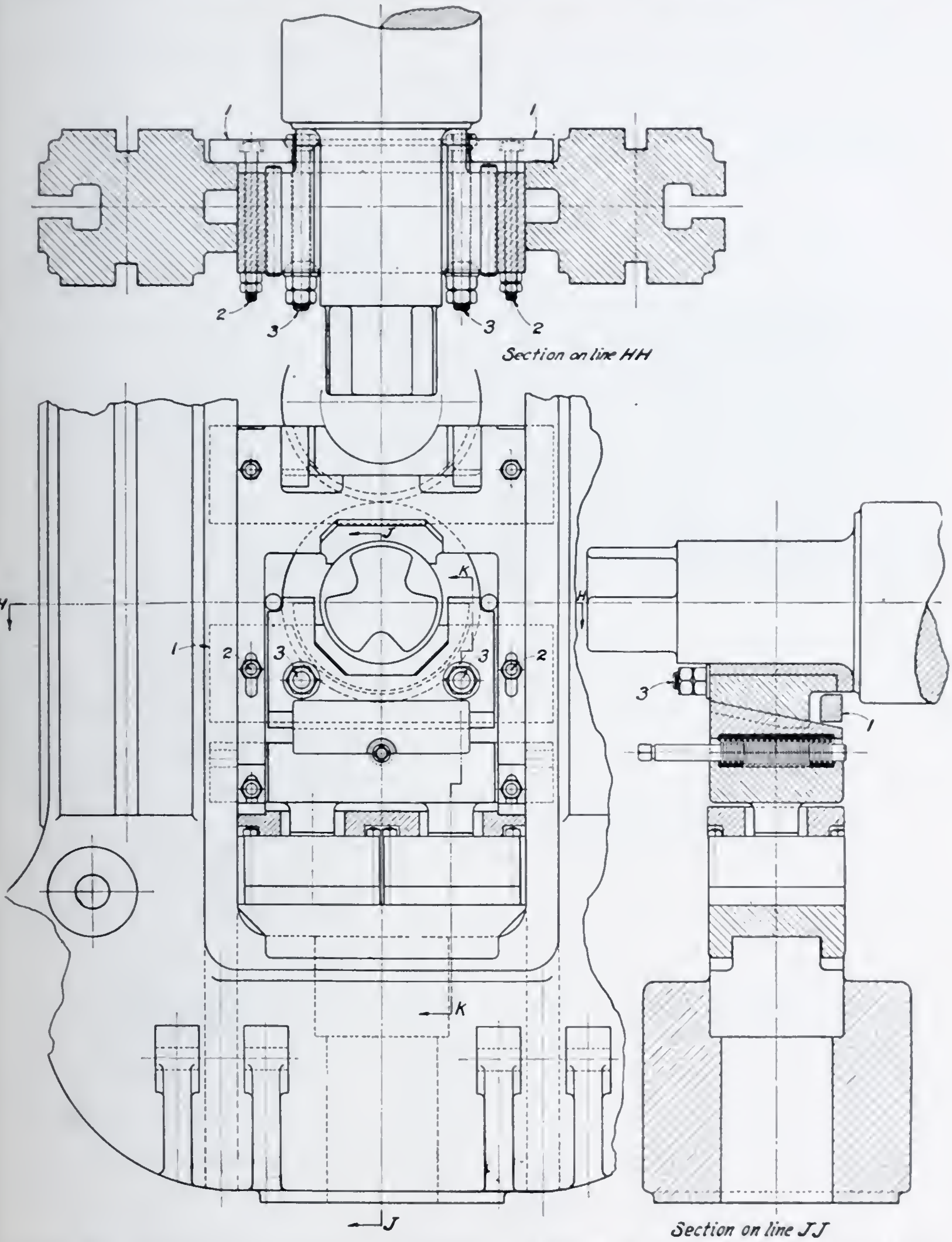

Fig. 20. Hydraulic Support Cylinders Applied to Three-High Bar Mill.

While readings from these cylinders will show conclusively what friction loss is sustained at the roll necks and what load is carried by both roll and housing, they will not record the losses in the transmission machinery between motor and roll. The measurement of these losses presents a second important problem. Fig. 22 and 23 show an exaggerated illustration of conditions at the roll-neck bearing and a method of locating the transmission losses when the rolls are under load.

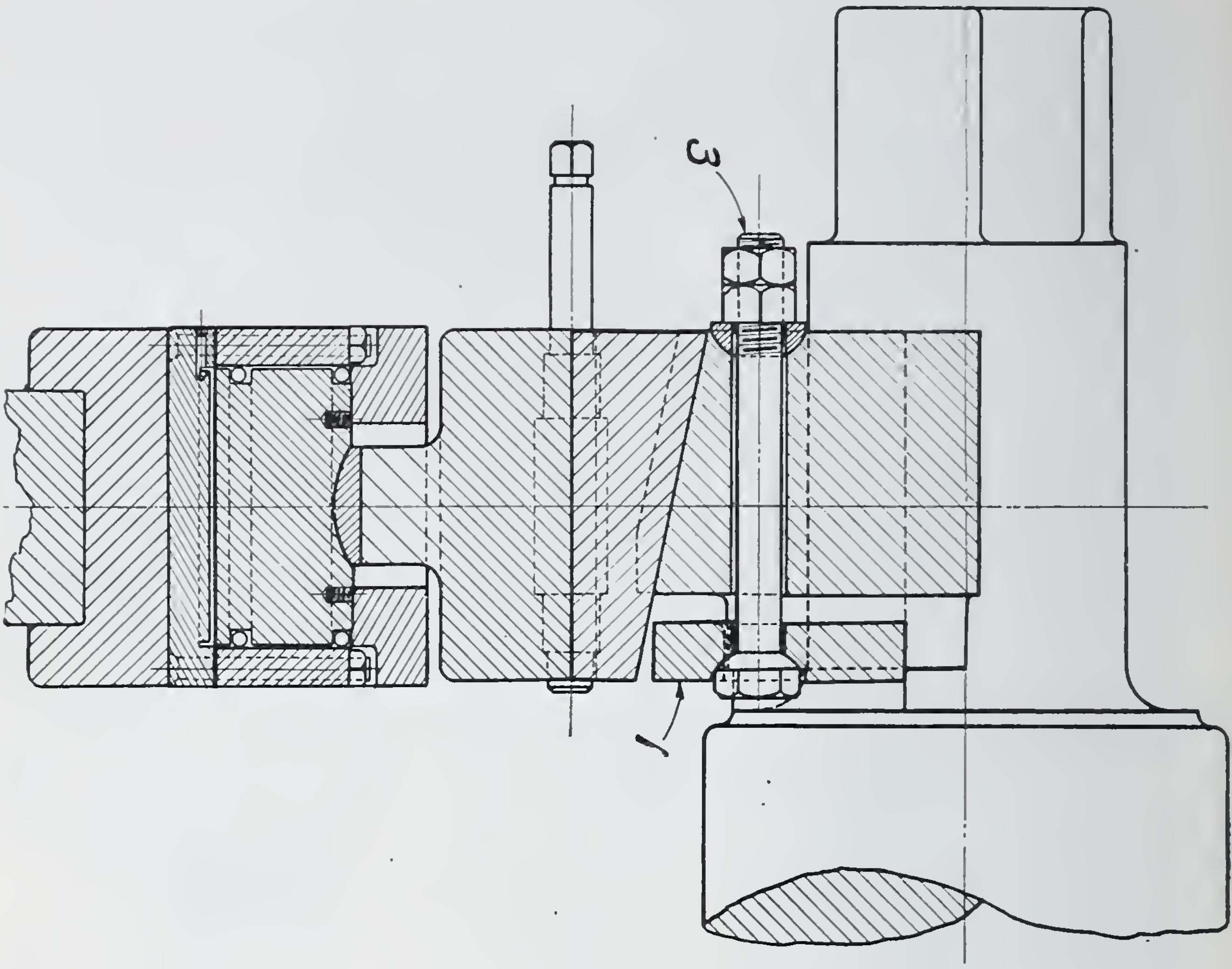

Fig. 21. Section on Line *KK* of Fig. 20.

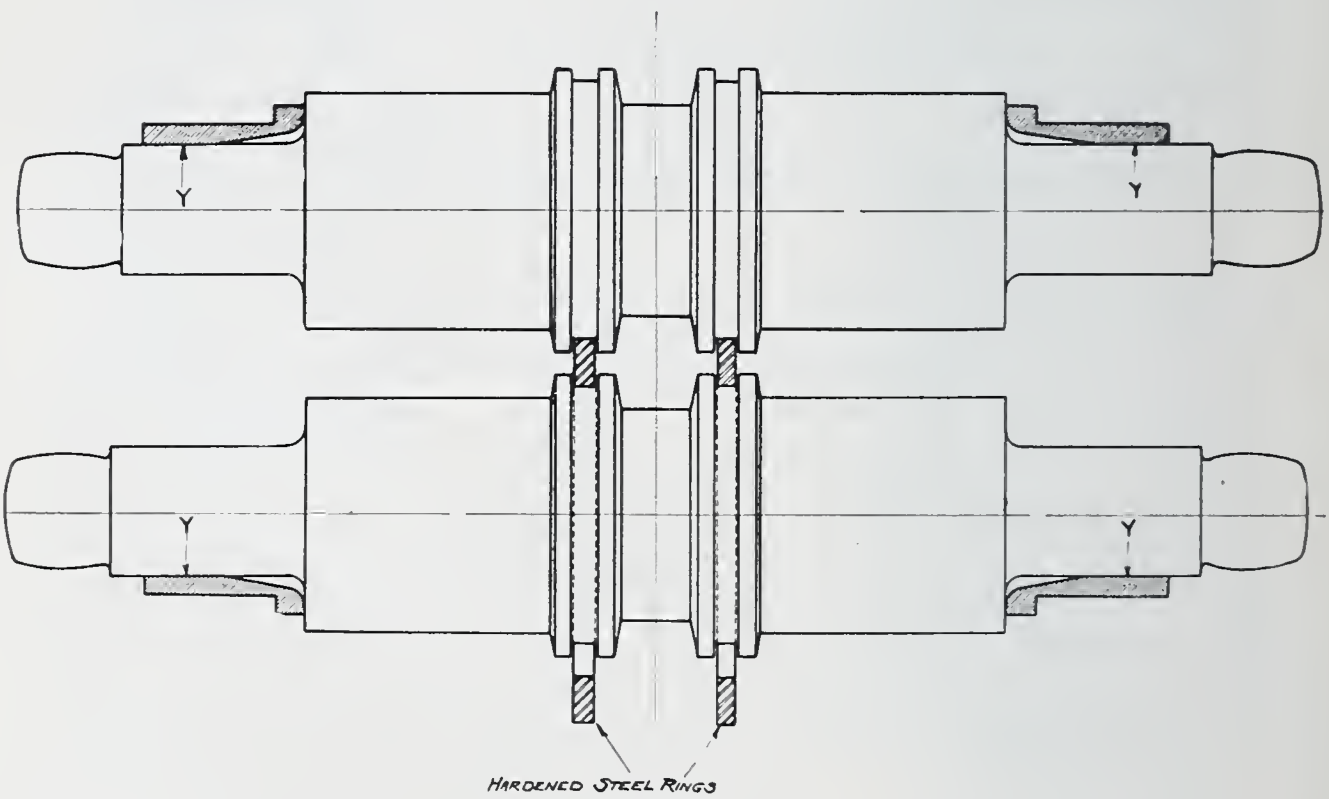

Fig. 22. Exaggerated Illustration Showing Application of Load to Neck Bearing.

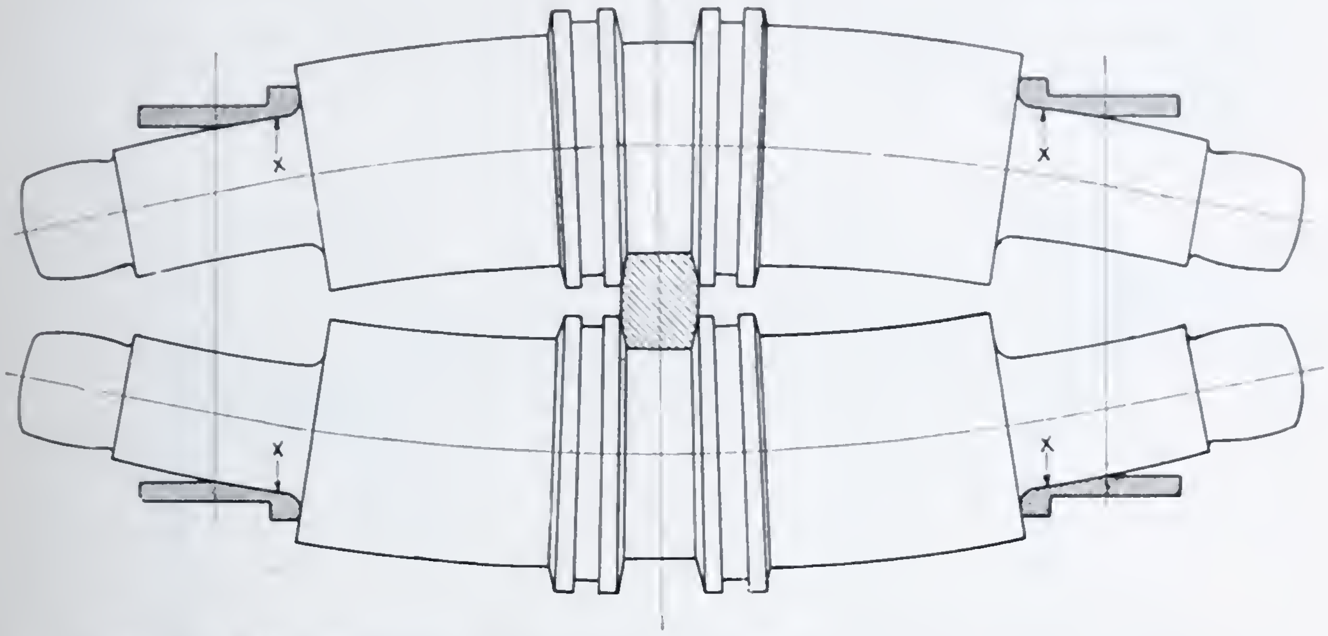

Fig. 23. Exaggerated Illustration Showing Application of Load to Neck Bearing.

When a bloom is being rolled, the heavy pressure between steel and roll causes the roll to deflect, placing the maximum pressure on the inside of the bearing as illustrated at *X* of Fig. 23, while the pressure is moved out as shown at *Y* of Fig. 22 when the roll is running light or is not deflected due to the bloom. It would, therefore, be useless to return the same load on the roll necks by means of the screws or hydraulic cylinders, unless a means is found to deflect the roll to the same elastic curve which it had when the bloom was being rolled, and by this means to restore the same conditions of roll-neck bearing and lubrication.

This can be done by inserting two hardened steel rings, *Z*, in grooves at each side of the pass as shown in Fig. 22 and then raising the pressure in the hydraulic support cylinders until they record the same pressures that existed during the rolling of the bloom.

The hardened steel rings will not elongate or change their shape, therefore no work will be done on them. The coefficient of rolling friction on machined surfaces of this kind is very low—low enough to be well within the allowable percentages of error. We will, therefore, have restored the loads on the transmission machinery, except for the net work required to roll the metal. The readings of the wattmeter will show the overall friction losses in the system and after motor losses are deducted the remainder will be the total loss in power due to friction losses in the trans-

mission machinery. The difference between the total load when rolling and the readings just described will be the net work required to roll the metal.

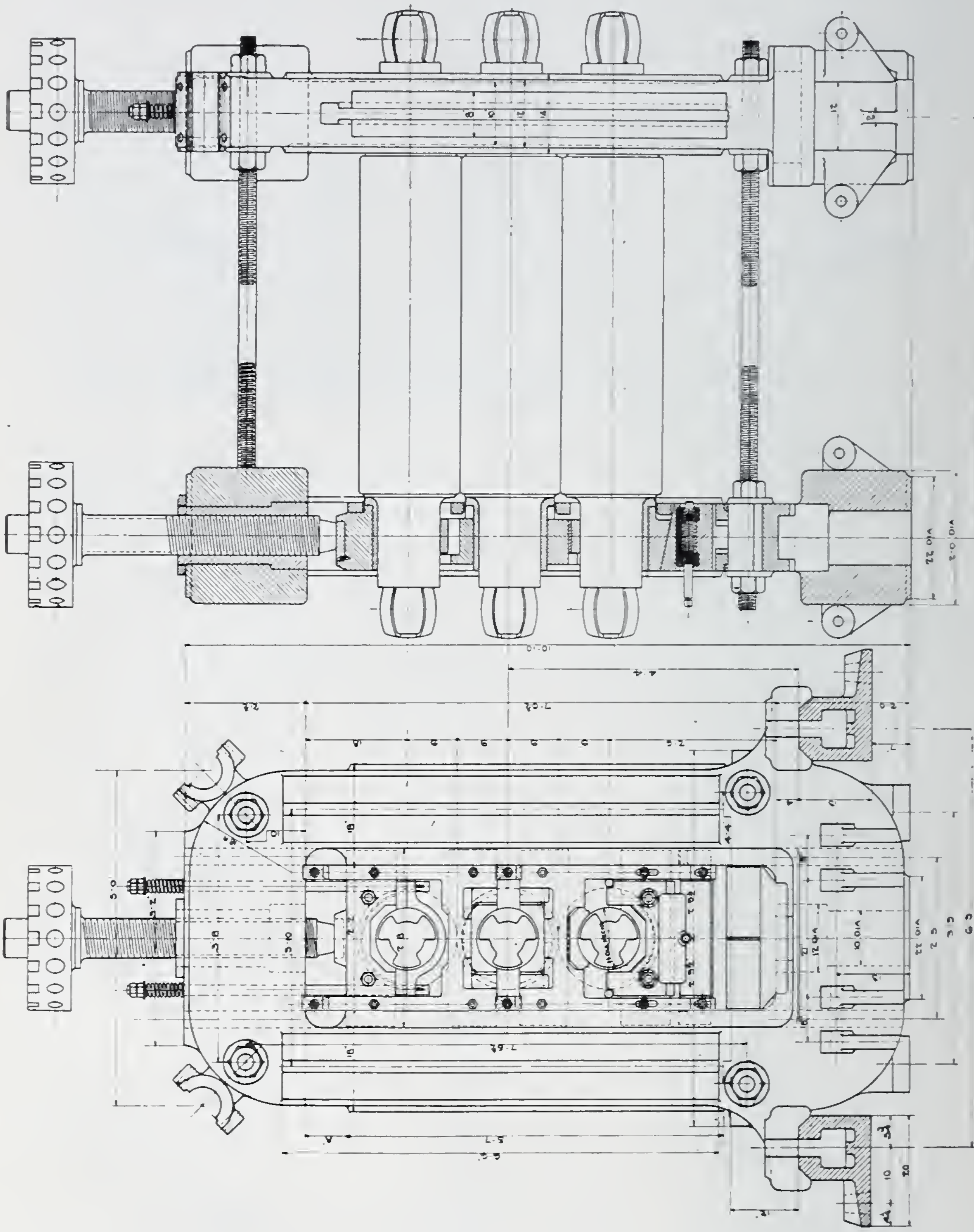

Fig. 24. Arrangement of 18-Inch, Three-High Bar Mill.

Fig. 24 shows an assembly of the closed-top housing when used as an 18-inch, three-high bar mill. The fillings are so designed that 16-inch rolls may be used with only a change in the neck brasses. Fig. 25 shows this same housing when assembled

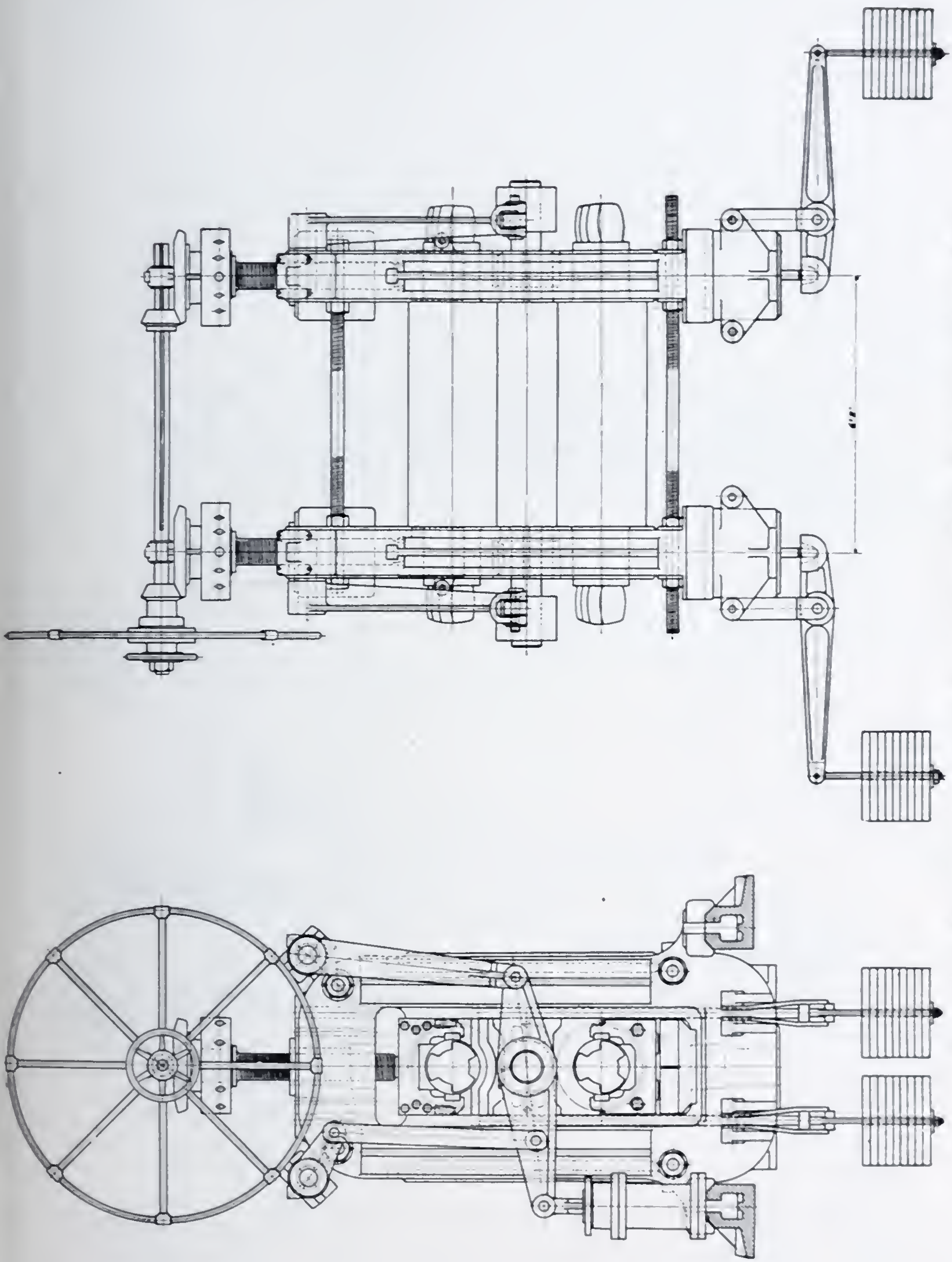

Fig. 25. Arrangement of 24-Inch, Two-High Balanced Sheet Mill.

as a 24-inch, two-high, balanced sheet mill. The roll-balancing mechanism may be omitted if work as a jump mill is to be done. The same fillings may be used for cold-mill work.

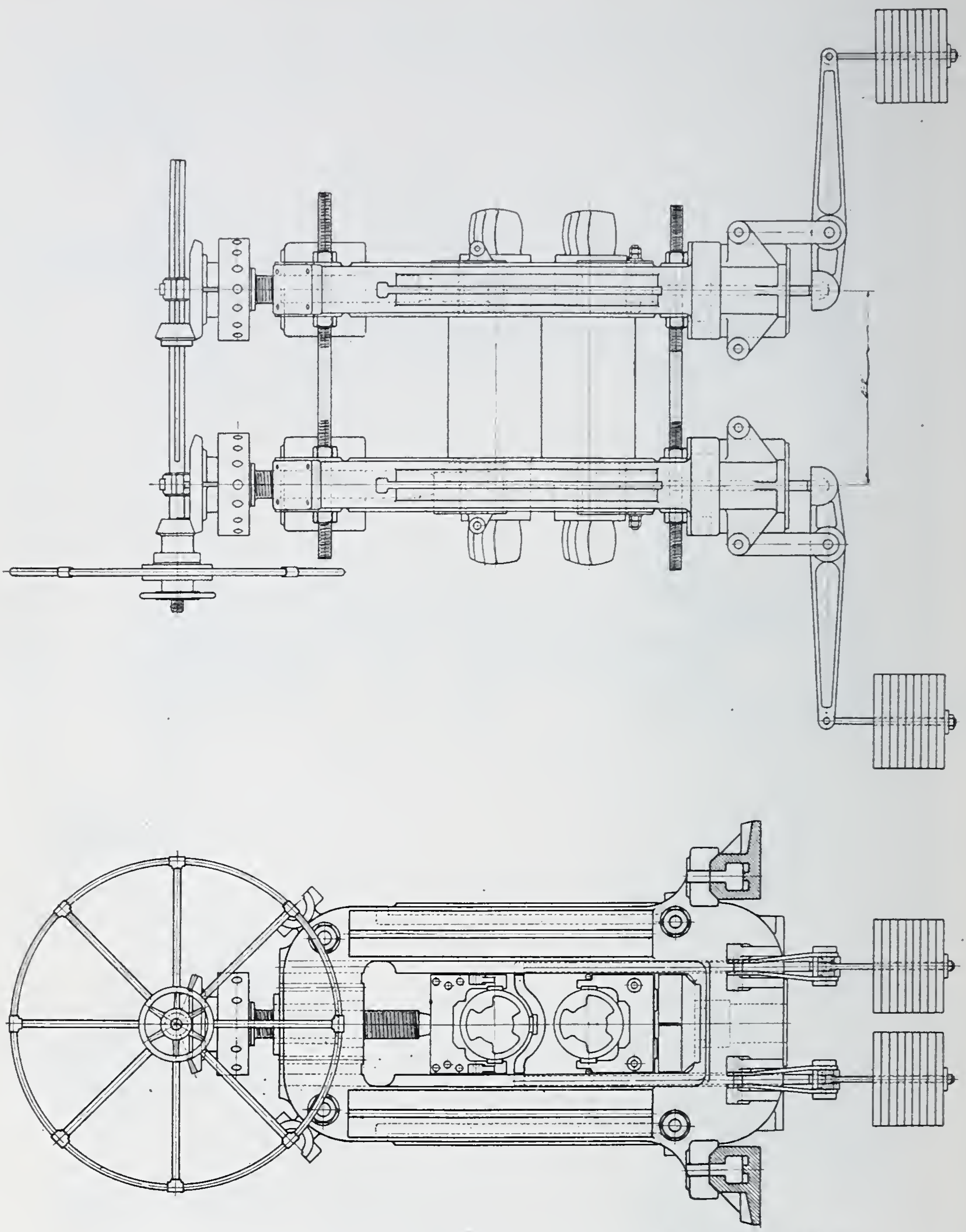

Fig. 26. Arrangement of 24-Inch, Three-High Plate Mill.

Fig. 26 shows the large housing assembled as a 24-inch, three-high, plate mill with 16-inch middle roll. The bearings at the top of the housing carry the cross shafts of the synchronizing mechanism for the middle roll. Cylinders to raise and lower this middle roll are bolted to the shoe-plate beside the housing. Fig. 27 shows a cross-section through the laboratory, with this mill connected with the drive.

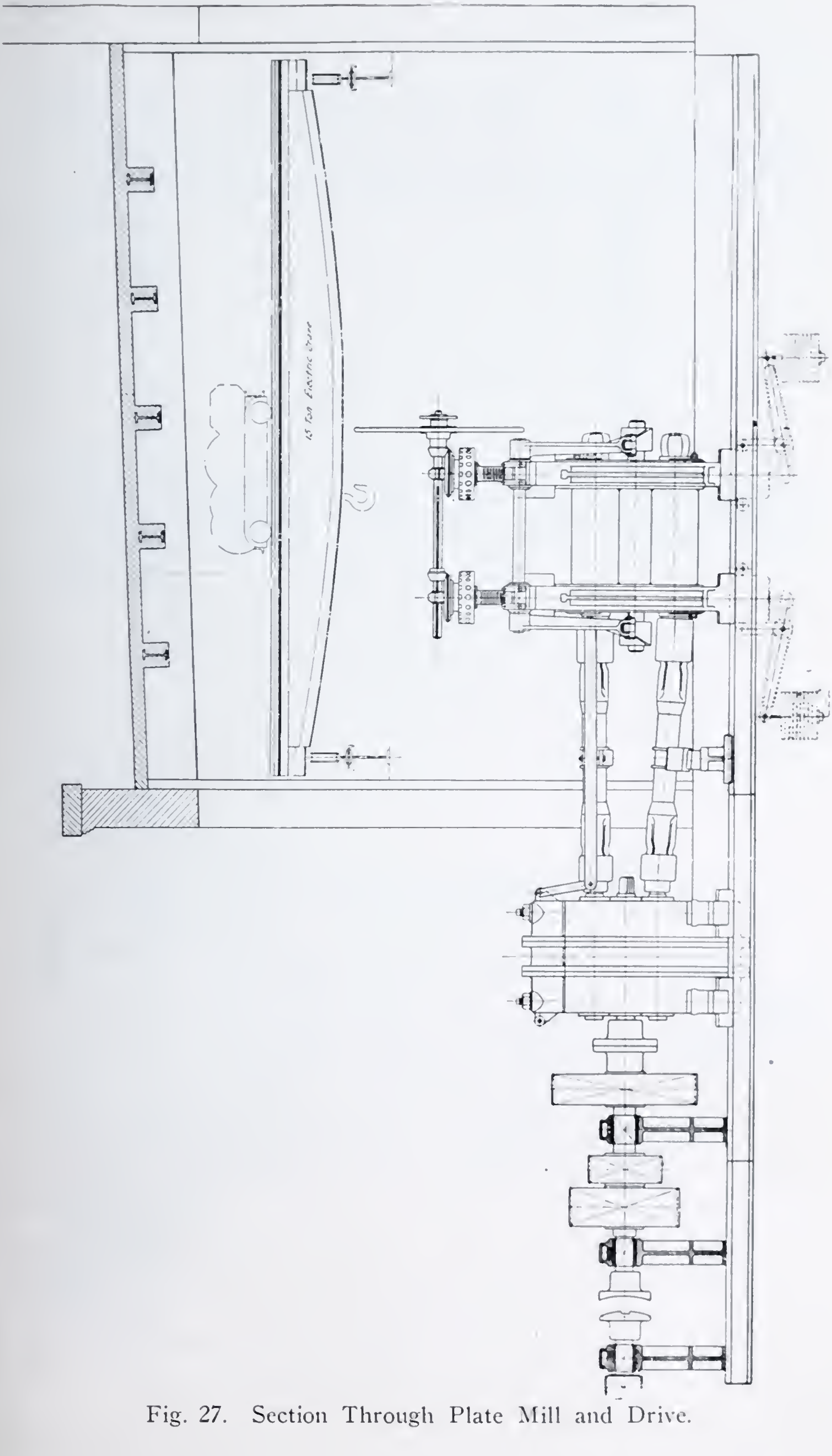

Fig. 27. Section Through Plate Mill and Drive.

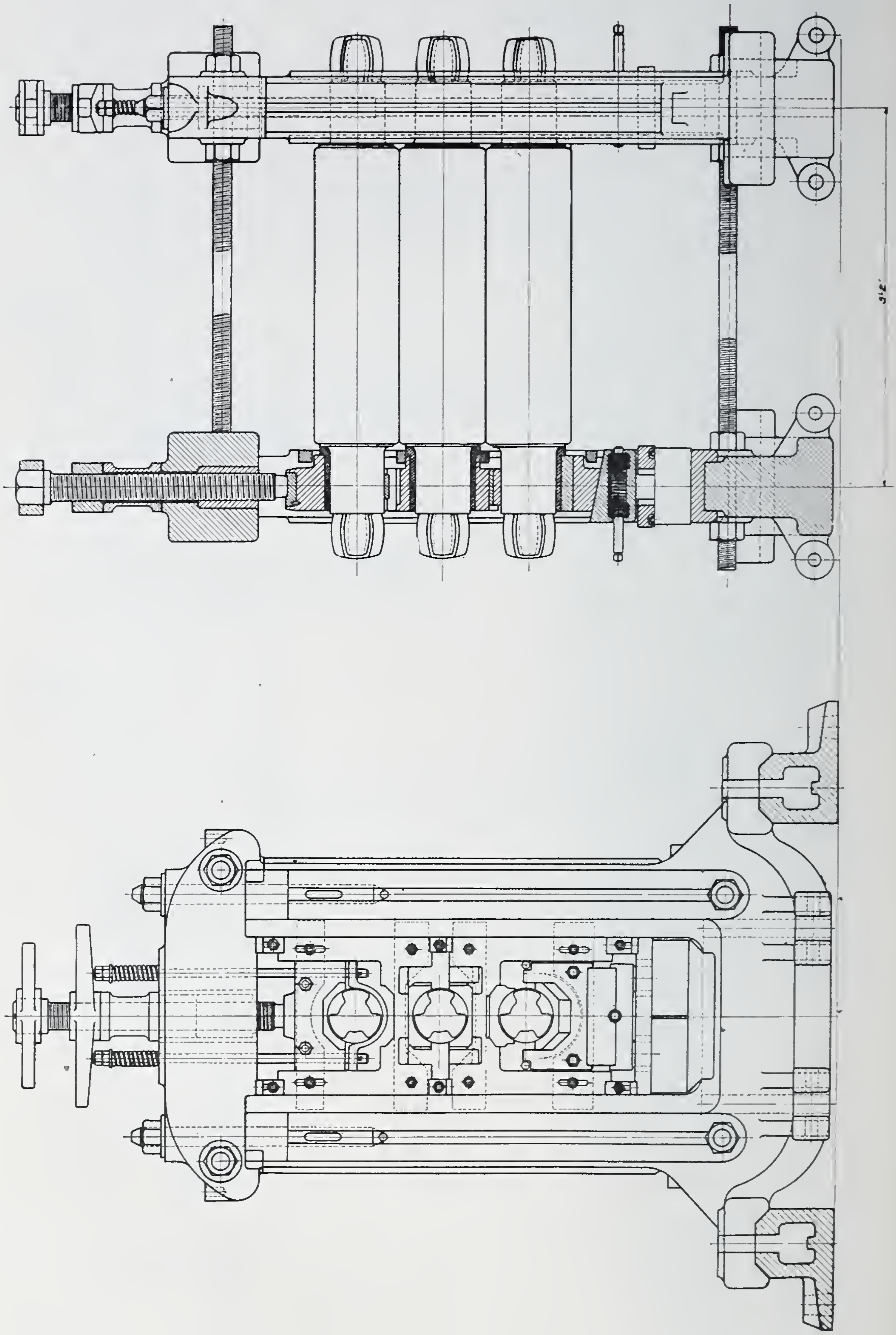

Fig. 28. Arrangement of 14-Inch, Three-High Bar Mill.

The middle roll and its operating mechanism may be left off and the mill assembled with either 24 plate- or blooming-mill rolls if it is desired to operate either of these types of two-high reversing mill.

Fig. 28 shows the assembly of the smaller open-top housing when used as a 14-inch, three-high bar mill. These same fillings may be used for either 12-inch or 16-inch rolls. A second set of fillings will be necessary for 10-inch rolls. It will thus be seen that we can assemble any size rolls between 10-inch and 24-inch diameter with necks between 6-inch and 18-inch diameter in at least one of these housings.

Fig. 29 shows the assembly of the pinion housing, which is made sufficiently large to assemble a combination of 24-inch top and bottom with 16-inch middle pinion, or 18-inch, three-high pinions, if desired. The housings also have a wide filler which may be changed to accommodate various widths of pinion face.

The heating furnaces will be just as carefully designed as the mill. At present we contemplate installing two furnaces approximately 3 by 12 feet inside, which will be either oil or gas fired. They will be fully equipped with a system of recording pyrometers, gas-meters and flue-gas analyzing apparatus, etc. Everything within reason will be done to equip these furnaces for careful work on fuel economy.

This concludes the mechanical features of the mill as far as they have progressed. Before bringing the paper to a close I would like to touch on the education and organization sides of the Bureau.

During the war, the Carnegie Instiutute of Technology had several thousand men stationed at the schools for short intensive courses to fit them for special mechanical duties with our army and navy. These courses were quite successful and men who had been selling ribbon, or who had been engaged in similar routine occupations most of their lives were taught to be motor or aeroplane mechanics in the short space of six weeks. The thought occured to officials of the Institute that if education of this character could be so successfully used in war, it could probably be used with equal success in peace.

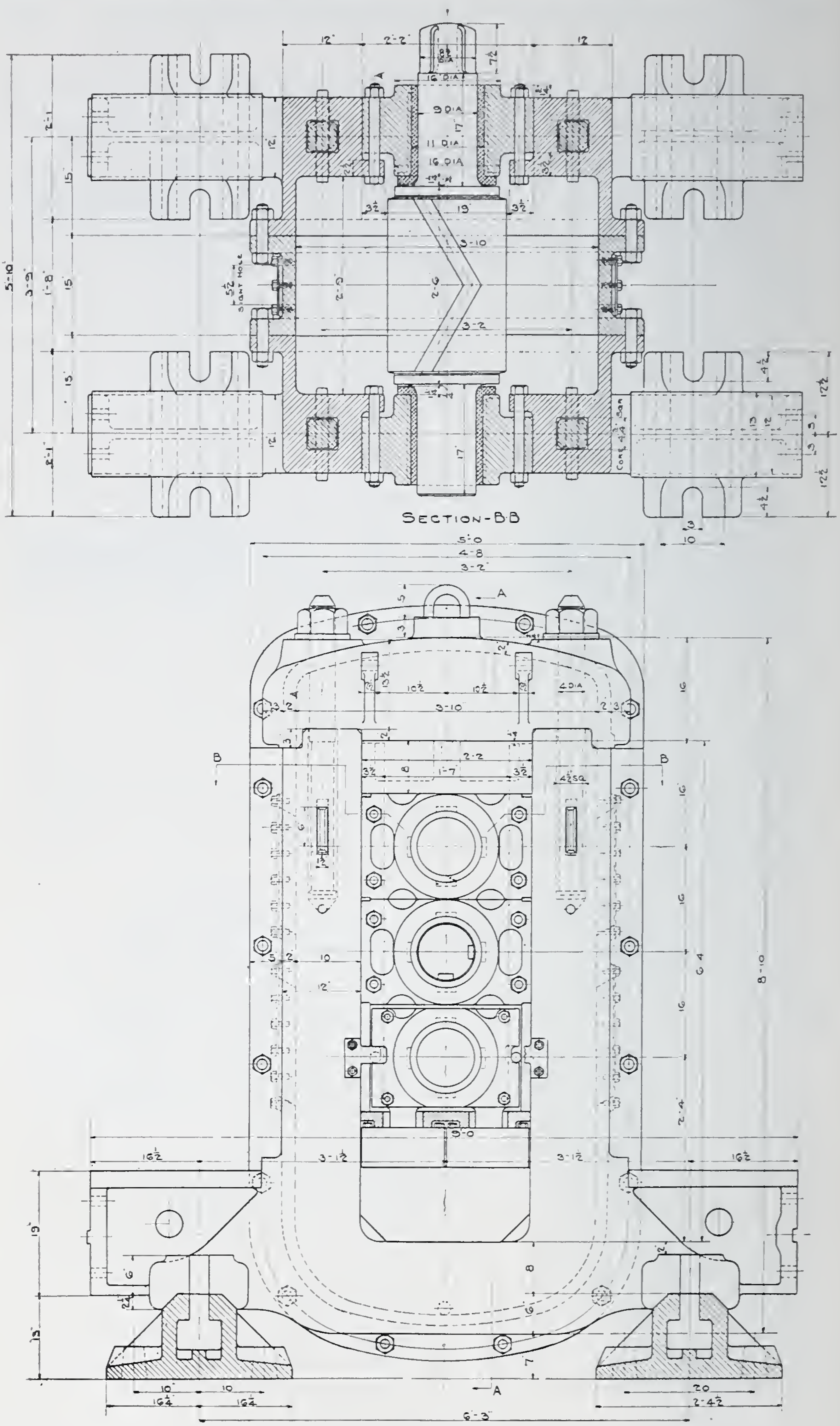

Fig. 29. Arrangement of Pinion Housing.

Almost every one is thoroughly familiar with the great amount of what might be termed "folk lore" connected with our mechanical processes. How many of you have talked, for example, with heaters who insist on queer notions regarding the burning of fuel in furnaces? Suppose we could take a group of these men for one week. Give them a lecture in the morning, a demonstration in the afternoon and a general discussion of the day's work in the evening. The theories of combustion and the chemical union of the elements entering into the reactions could be illustrated with circles, crosses and stars in colored chalk and made so plain as to be easily grasped. After a week of such training, these men would go back to the mills in far better shape to perform their duties intelligently than they were before they received the instruction.

Take, as a second example, a young helper on the rolls, who desires to become a roller. Before he can realize his ambition he must know just what causes each one of the many troubles that are continually occurring around a rolling-mill. He must also know just what to do to remedy this trouble. The place where he gets the largest part of his information is in the cobble pile. He may have to wait a year for some particular accident to happen before he can get a chance to study that particular combination of circumstances, and he must work for several years before he gets around the circle.

A series of lectures and demonstrations on a mill where tonnage was not a factor would give him, in six months of three nights a week, more experience than he could get in almost as many years of work on a producing mill.

With the reversing motor it would be easily possible to roll a short bar part way through a pass and then return it to the roller who could study the flow of metal from an actual specimen. The hot-saws on each side of the mill also permit the cutting of short sections of bar after each complete pass. These short sections could later be sliced into ¼-inch lengths and each man furnished with a sample of what actually happened in that particular pass. Demonstrations of faulty rolling as well as successful passes could also be made and the causes and remedies studied.

Throughout this paper the names "Bureau of Rolling-Mill Re-

search" and "Carnegie Institute of Technology" have been used side by side. The paper would not be complete without the statement that the two names denote separate and distinct organizations. The Bureau of Rolling-Mill Research is an organization of steel and equipment manufacturers and engineers interested in the manufacture of steel. It may also embrace firms manufacturing and rolling metals other than steel.

The Carnegie Institute of Technology is interested in the educational side of the work and is offering great inducements to such manufacturers for the purpose of locating the Bureau at the Institute. These inducements consist of furnishing the buildings with light, heat, etc.; use of the necessary power-generating equipment, such as boiler, engines and generators, and use of all the related laboratories. In addition, the Institute is furnishing funds for the initial financing of the Bureau's organization work until such time as a permanent organization can be formed and the Bureau established with a firm financial backing.

Space and time will not allow me to enter into a detailed discussion of the organization. The articles of association are available to anyone who wishes a copy.

DISCUSSION

Mr. C. F. Freeman:* Mr. Skinkle's paper certainly is very interesting. The outstanding feature of the experimental mill described in the paper, is its flexibility of adaptation for the many requirements which an experimental mill must have, to cover the entire field of shapes and sizes rolled in modern practice. Features such as this should induce numerous steel-mill owners to join in a movement to carry on the research work so long lacking in their field.

I recall that the Bureau of Standards at Washington installed an experimental mill for research work, a number of years ago. If Mr. Skinkle has any data, I would appreciate his comparing this mill with the mill described in his paper, and stating whether there are any conflicting ideas regarding the basis of research of the two mills.

Mr. W. B. Skinkle: In answer to Mr. Freeman's question regarding the experimental rolling mill of the Bureau of Standards at Washington I would say that I visited the Bureau when I first started to design the mill which I have described in the paper just read, and that I received a great deal of very valuable assistance from the men in charge of the work in Washington. All their difficulties were frankly discussed and I was warned to avoid several features which had given them some trouble. The ideas which I had to advance at that time were carefully examined by them and a number of suggestions made which have contributed quite materially to the designs which I have offered for your criticism to-night.

Their equipment consists of one stand of two-high, 16-inch mill which will take a roll body of about 66 inches maximum length. The pinions are two high with cut, herring-bone teeth, with the enclosed type of housing so that they can be made to run in oil, if desired. They have a heavy, well-designed gear reduction with all the gears of the cut, herring-bone type. The mill is driven by a 150-horse-power, four-to-one, variable-speed

*Sales Engineer, Mathews Gravity Carrier Co., Pittsburgh.

motor which gives a speed range, at the mill, of from 20 to 80 r.p.m.

At the time I visited the installation they had in stock only two sets of plain cylindrical rolls 16 inches in diameter, and 24 inches long, but inquiries were out at that time for an additional set of rolls for bar-mill work, which they intended to add to their supply. These new rolls were designed to roll ¾-inch, 1-inch or 1½-inch rounds from a 3½-inch square billet and were to have the roughing, strand, leading, and finishing passes all in the same body. I am unable to say at this time whether or not they have made any further additions to their stock.

The Philadelphia Roll & Machine Company, which designed and built the mill has very kindly furnished the attached illustrations of the installation. Fig. 30 shows a general drawing of the mill, and Fig. 31 is a reproduction of a photograph of the mill as it now stands in one of the buildings of the Bureau of Standards, at Washington.

The mill was built as one of the rush war projects for some special investigations on the rolling of light gun shields, and, I understand, rendered some very valuable assistance to the War Department and the Navy Department by this work. Owing to the pressure of war work for which the mill was installed, and the very short time allowed for its design, there are many features which would greatly facilitate research work on the rolling of iron and steel, which should be added before the mill can take up many of the general problems that are connected with the rolling-mill industry.

The officials of the Bureau of Standards have shown a great deal of interest in the work I have been doing and have cooperated with me very substantially in rendering aid on several of the perplexing problems that have arisen during the design of the "Tech." mill.

Mr. George H. Barbour:* The art of rolling has usually led, and seldom lagged far behind in the cumulative advances of the iron and steel trade.

*Mechanical Engineer, Fawcus Machine Co., Pittsburgh.

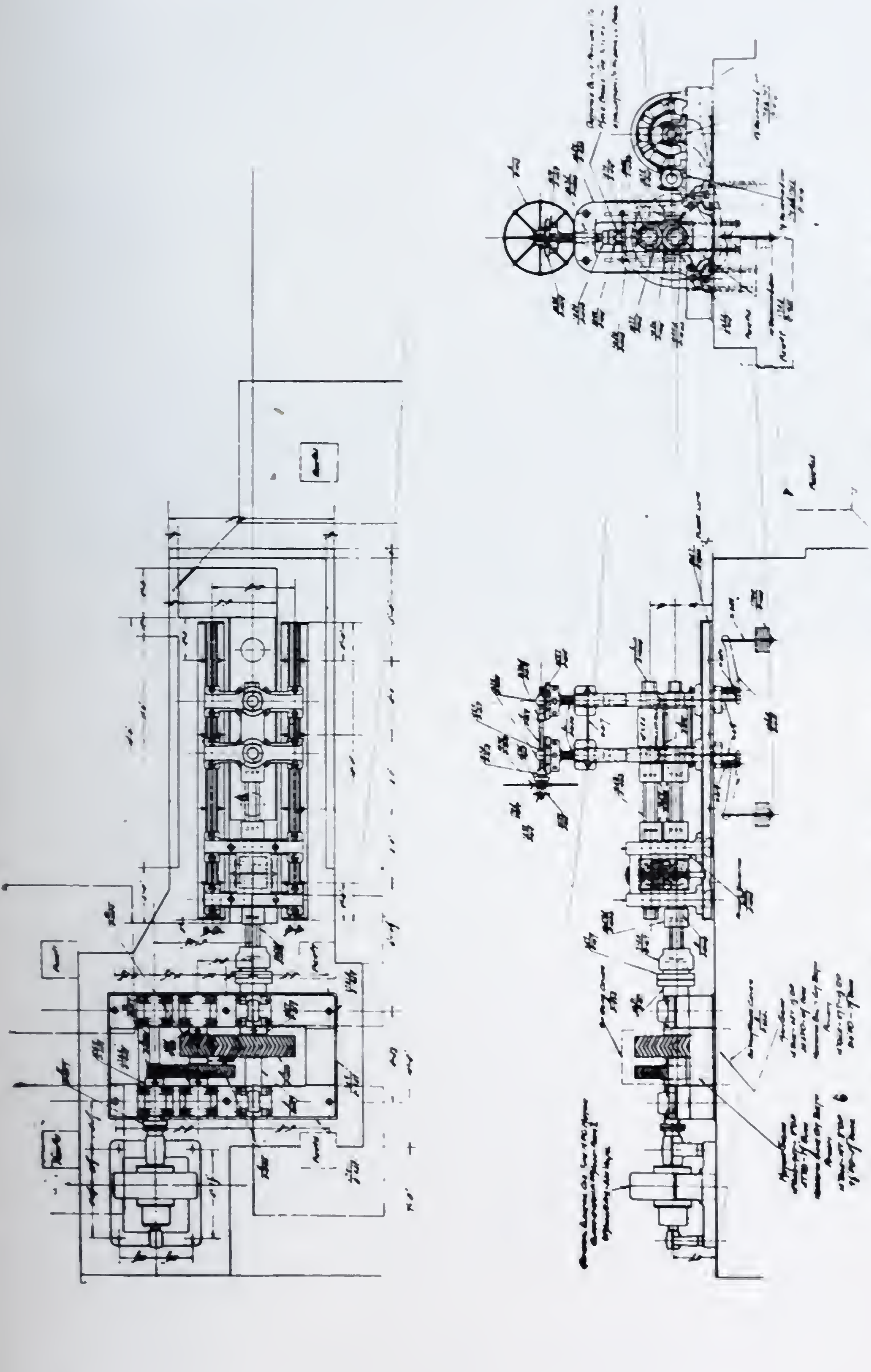

Fig. 30. Experimental Rolling-Mill, United States Bureau of Standards.

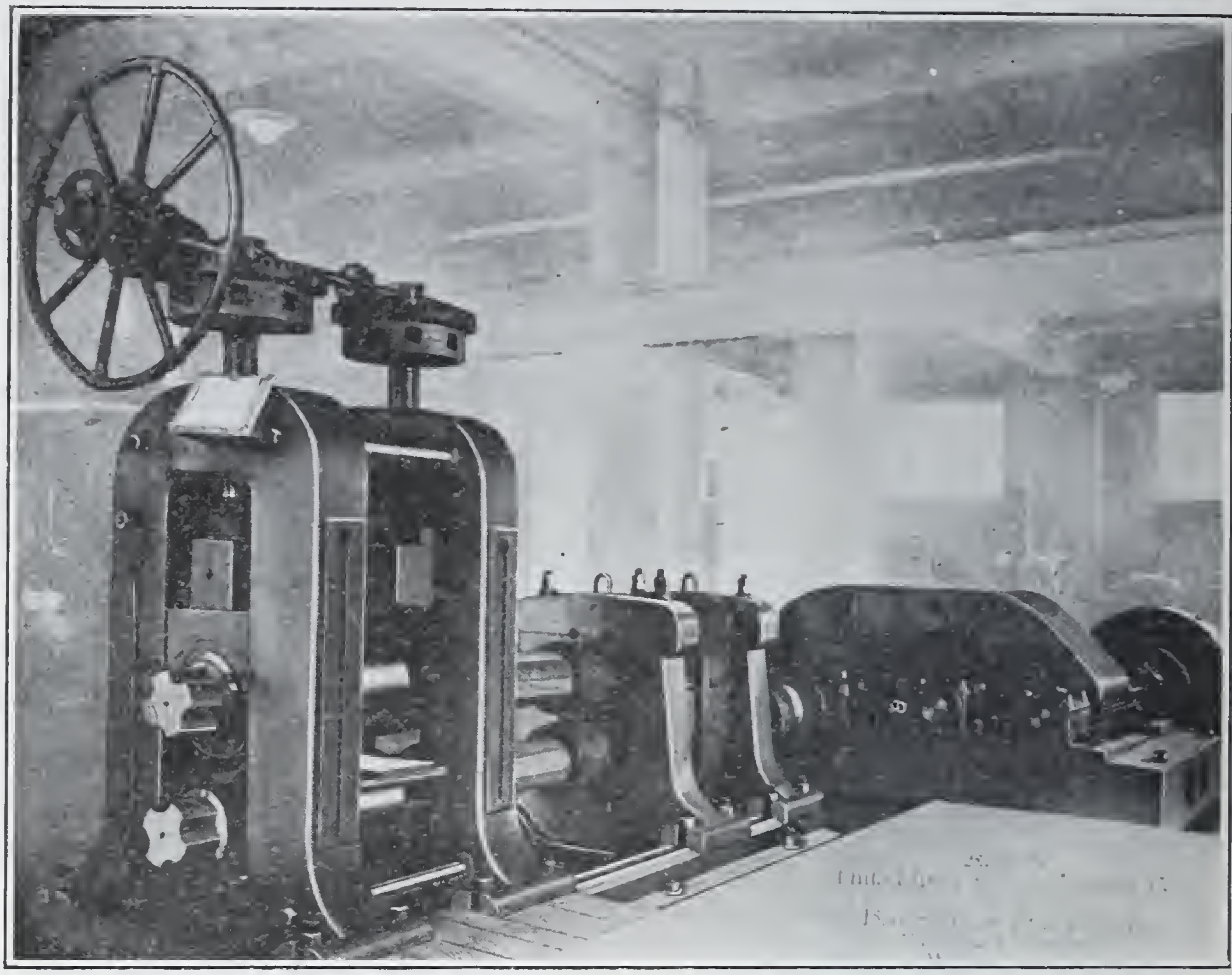

Fig. 31. Experimental Rolling-Mill, United States Bureau of Standards.

Prior to 1783 and 1784, when Henry Cort of Gosport obtained his patents for puddling iron and rolling it into bars, a British forge hammer could produce but one ton in 12 hours, and sizes under ¾ inch had to be cut on a slitting mill. Cort's rolls manufactured 15 tons of the larger and 5 tons of the smallest sizes in the same period, and contributed vitally to that rapid expansion in the uses of the metal which culminated in its application to the construction of ships in 1837, and to the stimulated production, especially in Scotland, resulting from the railroad boom in 1844, when stocks on warrants, in Glasgow alone, reached 450,000 tons. Great improvements were made in rolling-mills, both in strength and in design; the rolls were reversed to save time and labor; and Ramsbottom adopted Nasmyth's suggestion to reverse the engine itself, a practice soon adopted in every British works.

In America, where the Indians had no knowledge of iron, it was first forged in 1622 at a Virginia bloomery on the James River

which was soon destroyed by the savages. Installations of an iron mill at Lynn in 1631, a blast-furnace at Hammersmith in 1644, and works at Braintree in 1646, marked the inception of iron manufacture in New England; but when the Colonies began to export bar iron in 1717, an agitation sprang up in the mother country which ended in 1750 with the absolute prohibition, as a common nuisance, of the production of bar iron (nail plate) and steel in America. The Colonies continued to produce pig-iron, however, and between 1717 and 1770, exported about 150,000 tons of pig-iron and bar iron to England. The Revolution gave a great impetus to the trade; new works were erected; and all were busily engaged on war orders. With the return of peace in 1783, the trade was almost destroyed; the states became separate sovereignties with customs regulations often mutually hostile; the machinery of the works had not improved, notwithstanding the familiarity of Robert Grace and others with British practice; and coke had come into general use in Great Britain where the processes of puddling and rolling had superseded the forges. That country shipped iron to America duty free, while she herself levied an import duty of £3 19s. per ton; and in 1785, prohibited the export of any tools, engines, models or plans of machinery *used in making iron* under a penalty of one year's imprisonment, £200 fine, and confiscation of the articles shipped or *intended* to be shipped. This led to Hamilton's report of 1790 and the resultant adoption of the protective policy to encourage the infant industries of the country.

The system of internal improvements inaugurated by many of the states between 1825 and 1836, which permitted the transportation of coal and facilitated operations on an extended scale, marked the real beginnings of iron manufacture in America; for, previously, the Atlantic coast had been dependent upon British mines for fuel. Before 1840, the forges of Pennsylvania had abandoned the manufacture of bar iron and common boiler plate, which were being made in the puddling furnace and rolling-mill. The design of the machinery steadily improved, blowing-engines were soon made more powerful, and rolling-mill engines sufficiently strong to roll rails. In 1857, a three-high mill for rolling rails was installed at the Cambria Iron Works, and marked a de-

cided advance in the progress of roll designing and rail mills in general. On this mill, the first Bessemer rail order was rolled in 1867—a 4½-inch, 67-pound rail with a 4-inch base, from an 8½ by 6½-inch bloom, which to-day would be broken down from a 24 by 20-inch ingot. By 1870, the 4000 miles of railroad track of 1840, in the United States, had grown to 44,000 miles. During this period, a great deal distinctively American had been done in mechanical improvements of all kinds. The vigor and ability displayed in the inventions by which our iron trade had been supported, and, in the Bessemer trade at least, placed at the head of the world, deserve the highest praise. In fact the mechanical had far overshadowed the metallurgical side of the art. From then on, attention was to be paid more and more to improvement in processes by the universal application of chemistry in the interests of economy and improved quality.

Formerly, when tonnage was but a minor factor, the roll designer was satisfied simply to produce the required section; 70 tons of rails in 12 hours constituted a big turn, 40 tons of structural shapes a good 12-hour run. Now, 1600 and 1200 tons, respectively, are not exceptional; and the roll designer successfully faces such complicated arrangements as tandem mills, and zig-zag layouts, with applications of separate engines and motors driving at the greatly increased speed required to produce these enormous tonnages. He must provide for squeeze, spread, elongation, and bend with successive drafts appropriate to the number of passes and strength of his mill and the power of its drives, and with due consideration for steels of different grades; for, though a perfect section may be obtained with little difficulty from steels of mild quality, success will not always follow with steels that are hard and stiff, and which neither spread nor flow readily, especially in flanging. The heating of the steel also must be considered, as different steels require different temperatures. Proper initial heat is essential to success, and material not properly heated wears and breaks the rolls.

While the design of consecutive passes for the simpler, symmetrical, commercial sections and the determination of their power consumptions might be reduced to somewhat of a science, there is a growing multitude of complicated and unsymmetrical shapes

such as will now be exhibited, which are bound to remain an art, and more or less of a mystery, except to the adept, the experienced and the initiated.

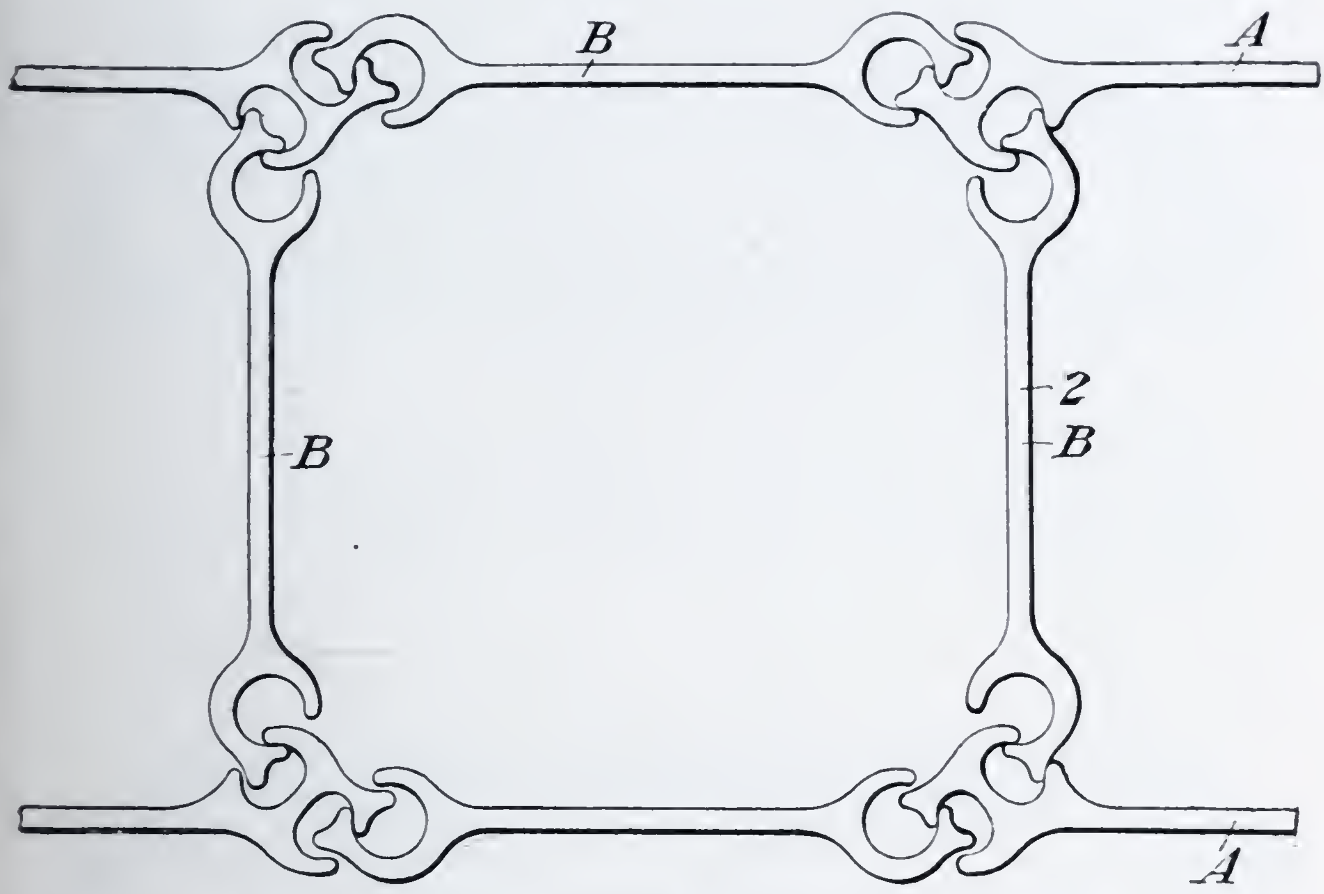

Fig. 32. Combination of Two Forms of Sheet Piling.

Fig. 32 represents possibilities in the construction of cofferdams, etc., with the simple piling shown next the top of Fig. 33 and the universal locking section shown at the bottom of the same figure—for which the sections at the top and next to the bottom, respectively, illustrate the leader passes. Fig. 34 illustrates the successive passes for producing the leader section for the Universal Interlock. Fig. 35 shows the types of girder rails in common use, and Fig. 36, the side roller arrangement for producing their grooved sections. Fig. 37 and 38 illustrate possibilities of the angle method of rolling when carried out at 45 degrees. Fig. 39 and 40 illustrate rolls applicable to ordinary housings, in which the pass is adjustable for successive reductions by means of ordinary vertical screw-downs. Such rolls being self gaging and readily adjustable to a hairsbreadth, permit the manufacture of beams in a tandem arrangement of passes, and, therefore, their production in lighter gages on account of the speedier operations.

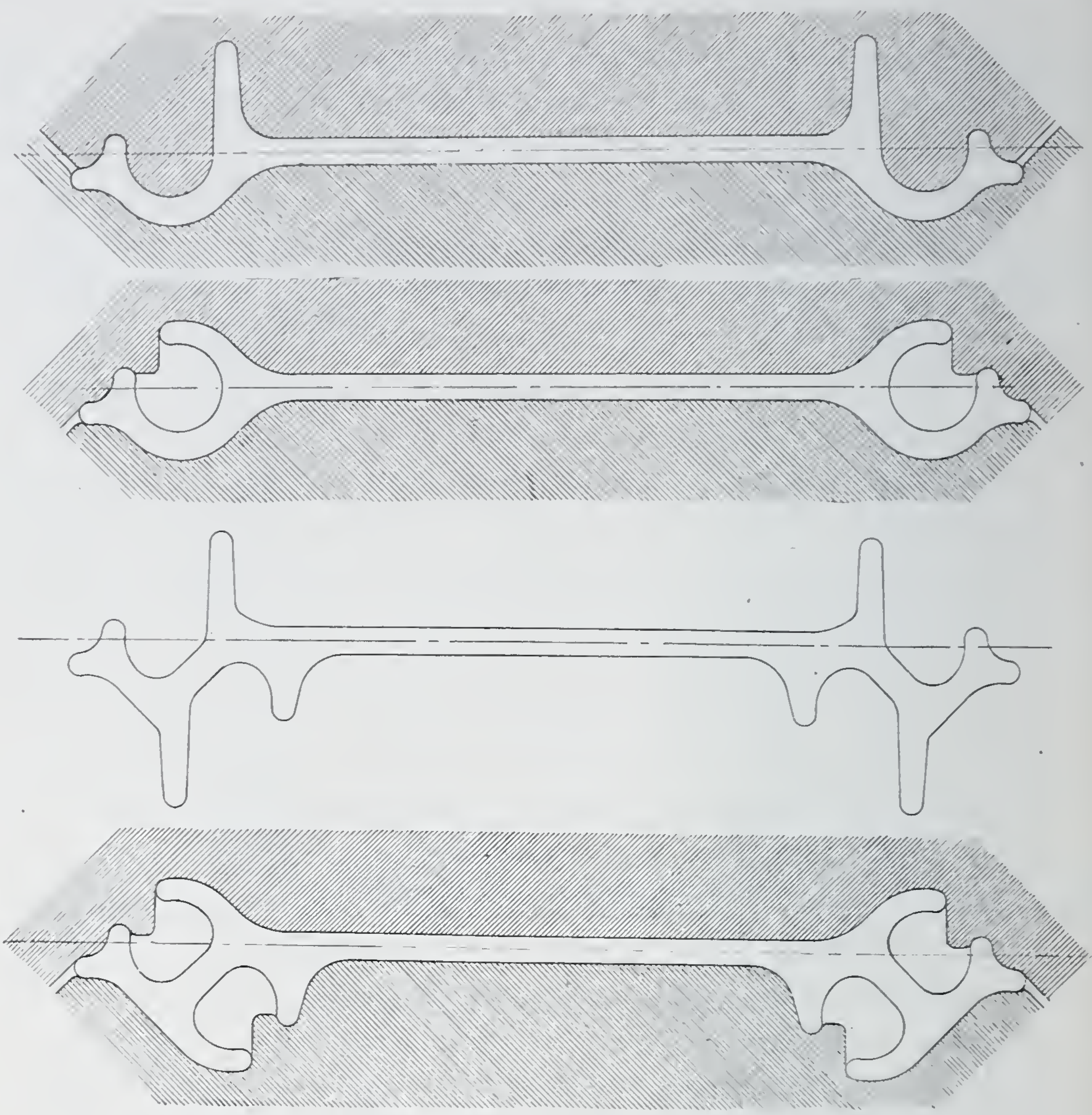

Fig. 33. Leader Passes and Finished Forms of Sheet Piling.

Such of the collars as were not keyed would naturally revolve at their respective speeds of least resistance, which would materially reduce the tear and distortion of the extreme fibers of the section. Fig. 10 and 11 illustrate, diagramatically, the successive reductions obtainable by such a method.

Primarily, a rolling-mill is a commercial proposition, and, given one of a certain power, diameter, strength and speed, its proprietor is going to operate it to meet the exigencies of his trade, and, notwithstanding his desires and endeavors to run with the least consumption of power, he is bound to recognize his order schedule, delivery obligations, raw material supply, wage scale, and labor limitations as vital and determining factors.

Continuous operation at maximum capacity is the acme of

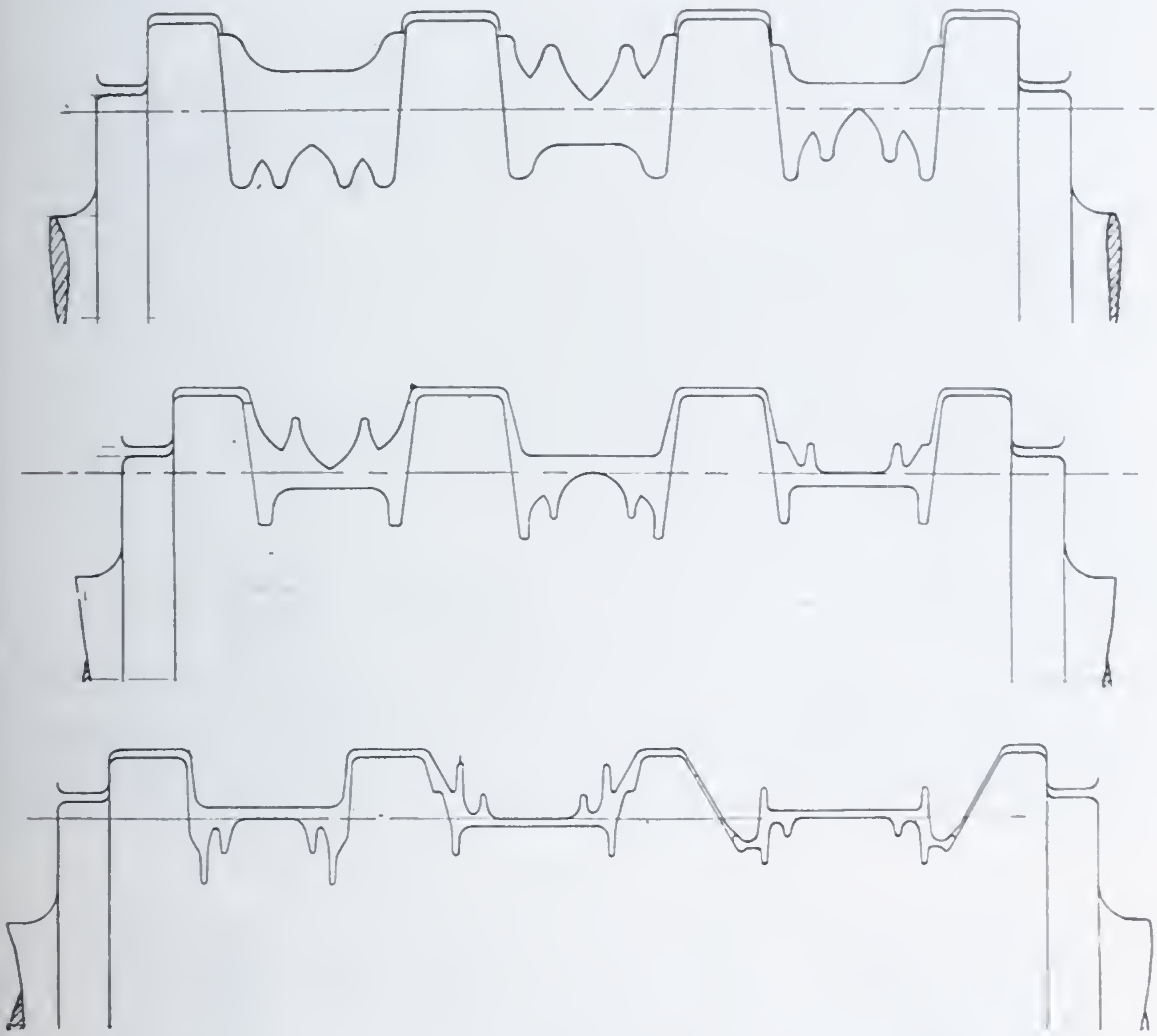

Fig. 34. Successive Passes for Leader Section, Universal Interlock Piling.

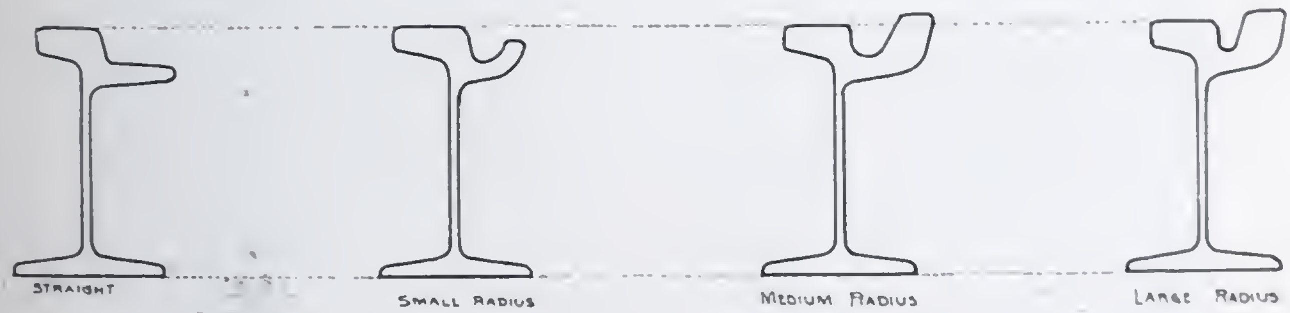

Fig. 35. Section of Common Girder Rails.

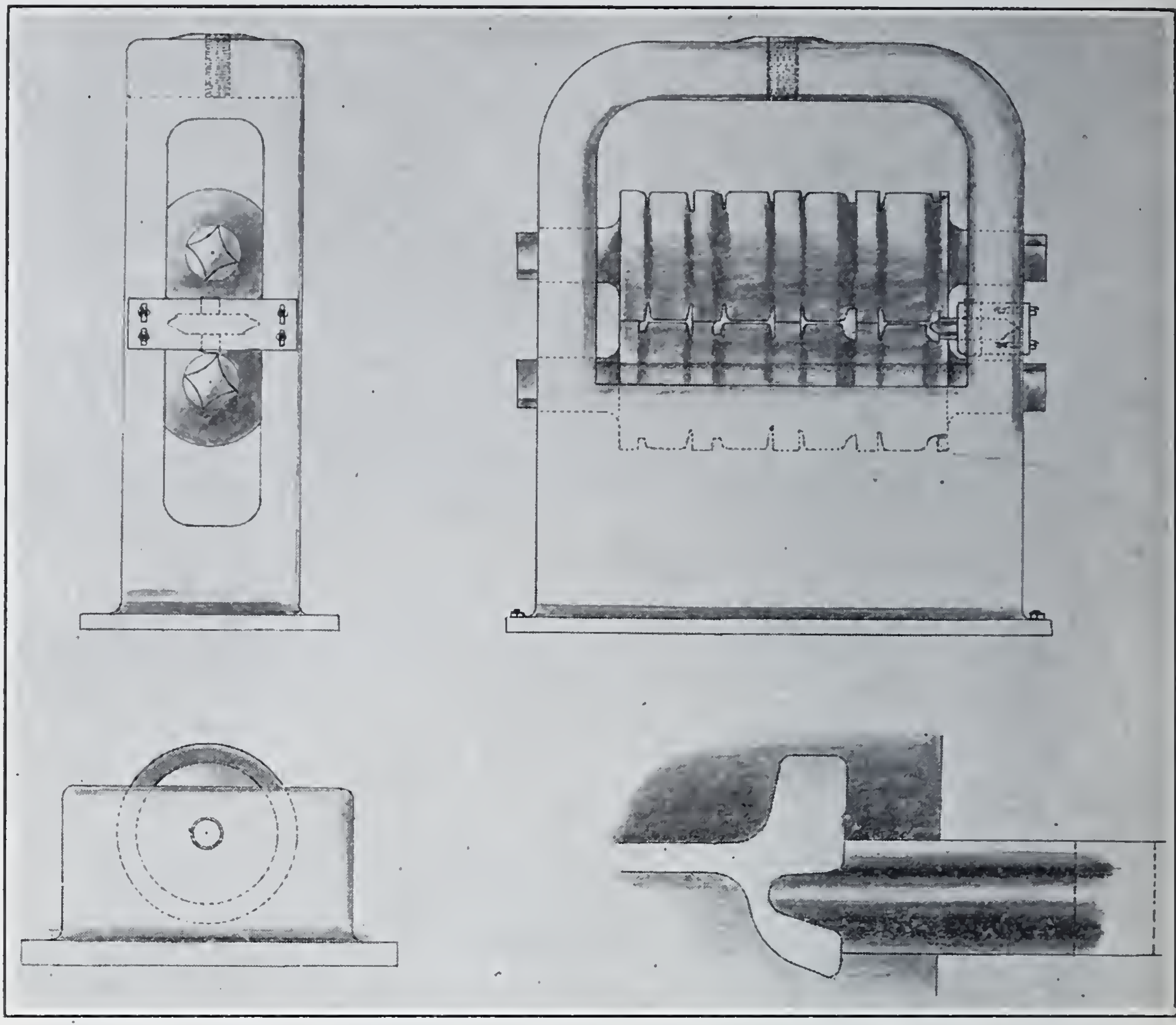

Fig. 36. Side Roller for Rolling Grooves in Girder Rails.

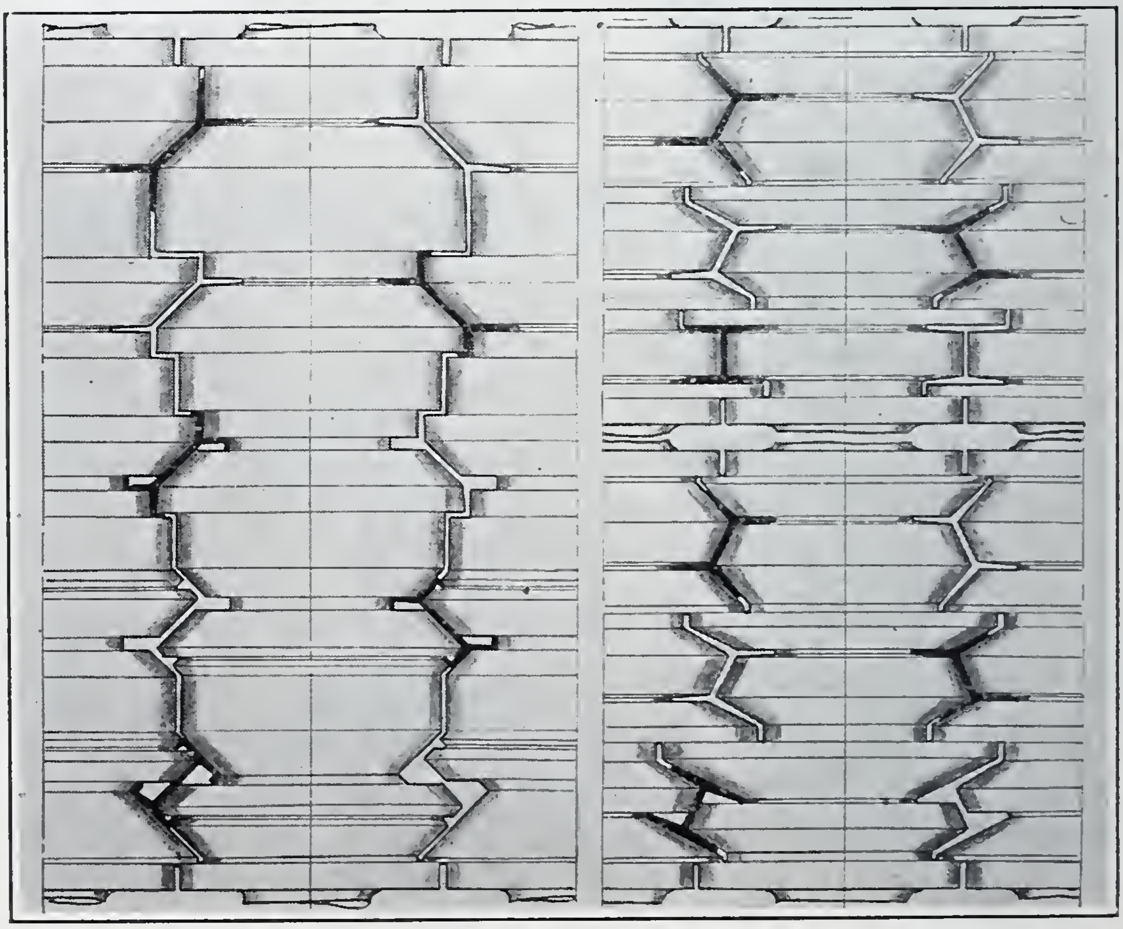

Fig. 37. Possibilities in Angle Method of Rolling.

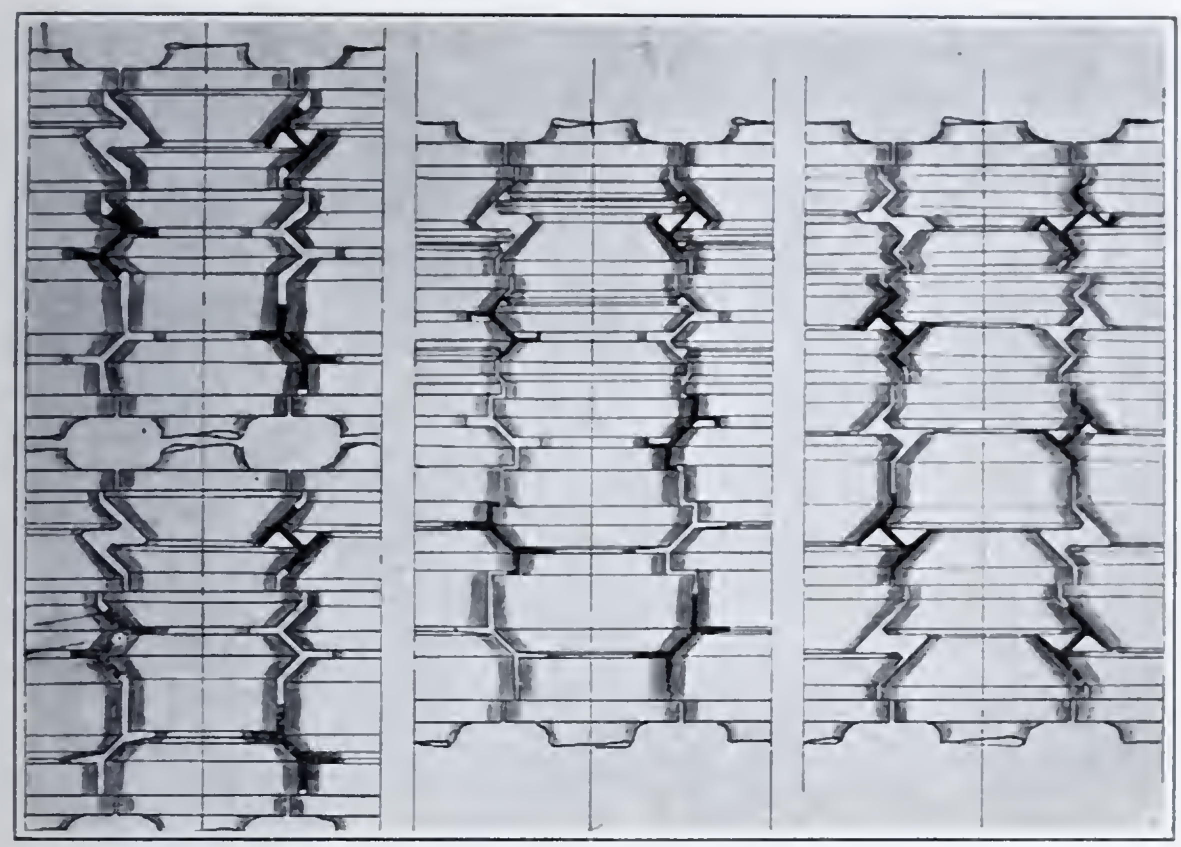

Fig. 38. Possibilities in Angle Method of Rolling.

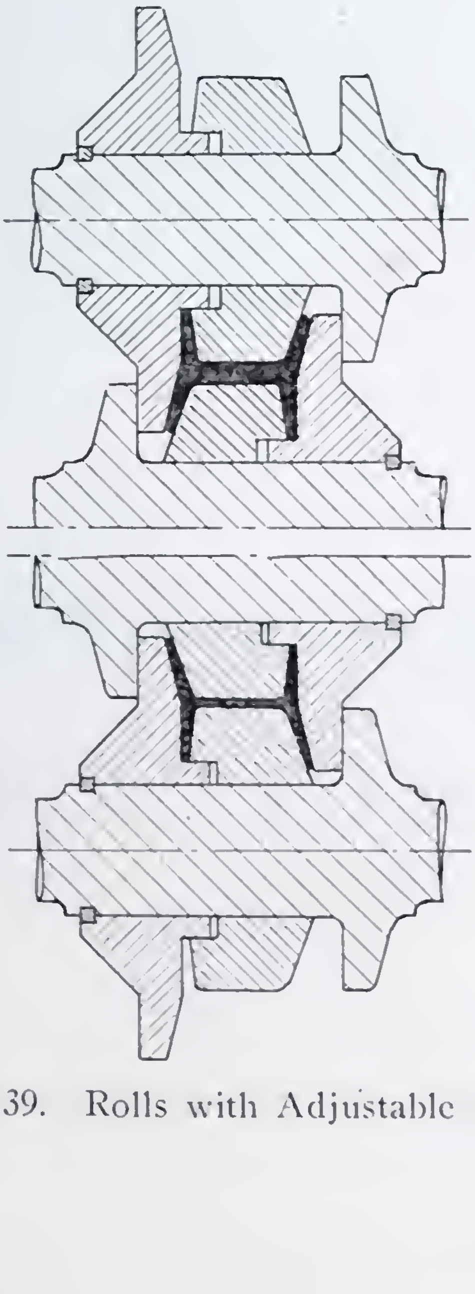

Fig. 39. Rolls with Adjustable Pass.

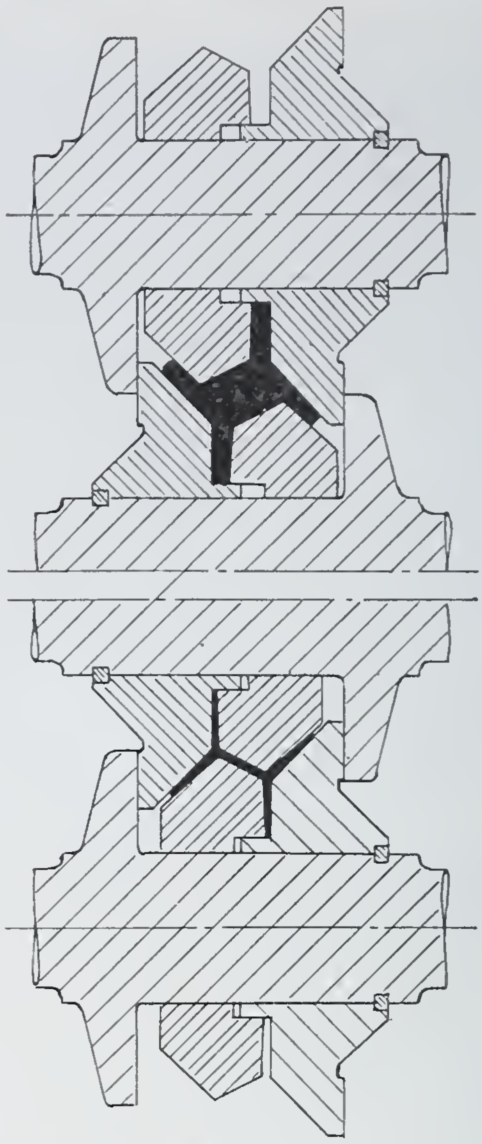

Fig. 40. Rolls with Adjustable Pass.

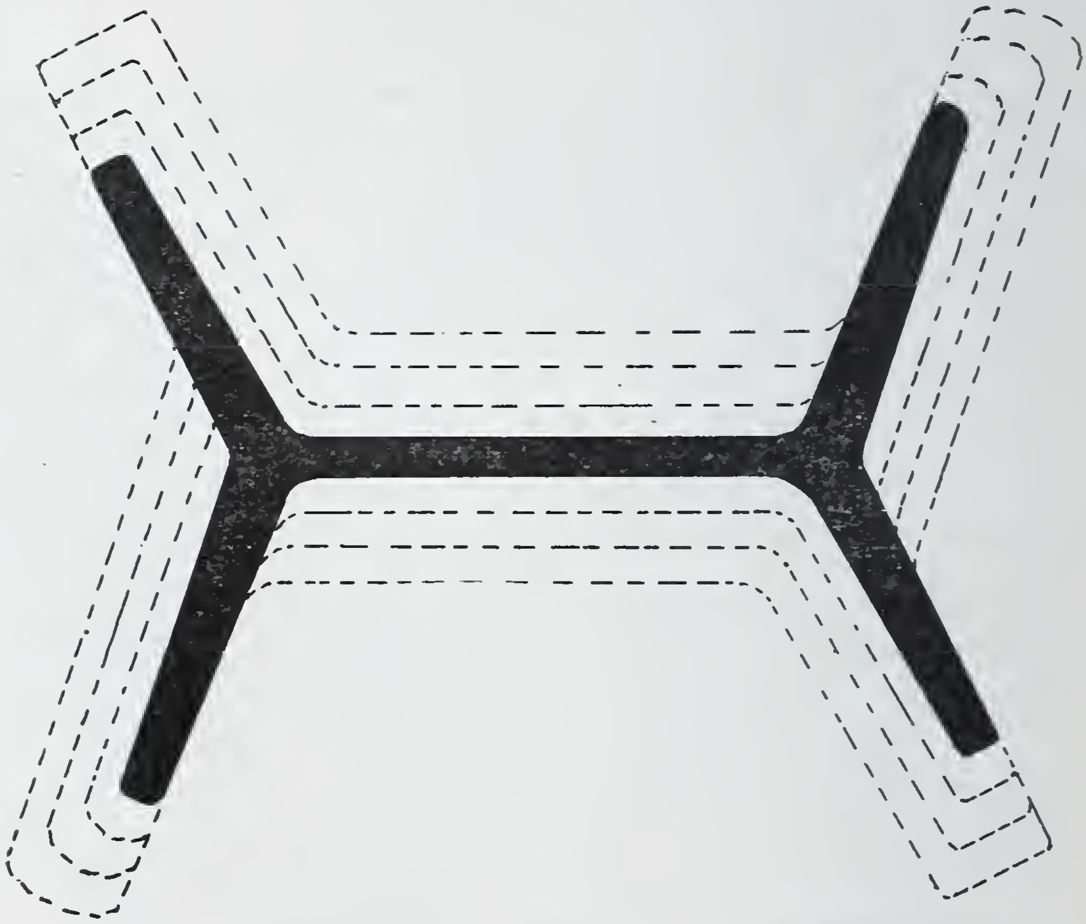

Fig. 41. Diagram Illustrating Successive Reductions.

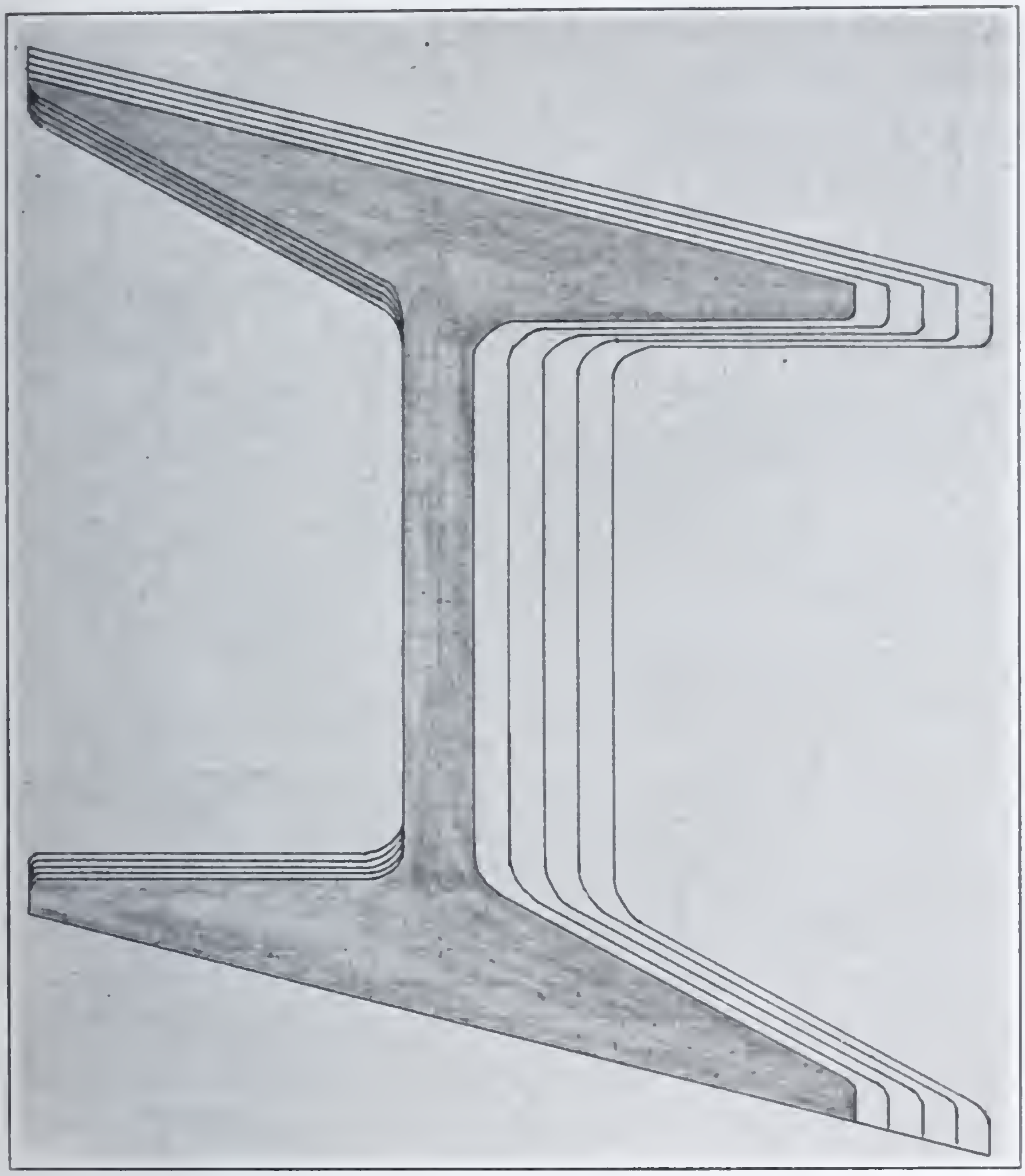

Fig. 42. Diagram Illustrating Successive Reductions.

rolling-mill economy, while roll changes, breakages, short orders, difficult sections, mill repairs and the thousand and one contingencies which delay and reduce production are its cruces.

Mr. W. B. Skinkle: Mr. Barbour's remarks on the historical side of the development of the iron and steel industry are very interesting and instructive, and form a valuable addition to this paper. The cuts which he offers on complicated and unsymmetrical sections represent, to my mind at least, the highest development of the art of rolling steel.

It would be hard to imagine a more advantageous place in which to continue the development of such rolls, than that offered by the experimental mill described in the paper which I have just

presented. Tonnage would not be a factor in this mill and the very wide speed range, together with the ability to reverse the direction of rotation would offer exceptional opportunities to study the action and flow of the metal under a very great variety of conditions.

Another feature which offers a large field for development is the rolling of more complicated sections in continuous mills. As Prof. Trinks explained in his paper, the action of metal when worked in rolls is complicated by so many variables that it defies a purely theoretical analysis. In continuous-mill work the design of roll passes is further complicated by the addition of another factor known as the "controlling diameter," or that diameter which when multiplied by 2π times the cross-sectional area delivered from the rolls will give the volume of steel delivered per revolution. The difficulty of ascertaining this "controlling diameter" has limited the product of continuous mills to strips, sheet bar, pipe skelp, rods, merchant iron and similar simple symmetrical sections in spite of the large tonnage and low labor cost that result from their use. I have the preliminary sketches of a device which will fasten onto the delivery guide box of a mill and will mark the section delivered, once for each revolution of the rolls. With such a device installed, a new design of continuous-mill rolls could be tried out in the experimental mill when it is assembled as a hand-fed bar mill as shown in Fig. 14. A bar ten or twenty "revolutions long" could be rolled and marked off as described, and the length and cross-sectional area measured from the actual piece which was delivered. The figuring of the controlling diameter would then be a simple matter. The particular advantage of this arrangement lies in the fact that the controlling diameter obtained in this manner would be uninfluenced by the effects of stretching or crowding resulting from the influence of other passes in series with the one being studied.

With this information at hand, the rolls could then be measured and, if necessary, given a final turning in order to bring their diameters into correct relation. The housings could then be assembled as a continuous mill as shown in Fig. 9 and 10 and the rolls tried out under the conditions of actual operation. Much time and money could be saved and the number of sections which

could be rolled on a continuous mill greatly increased if such a method were followed.

MR. N. A. DOYLE:* I am not competent to criticize Mr. Skinkle's paper from a technical standpoint—that I perforce leave to those who are; but I find myself very much in sympathy with the general idea on which the proposed Bureau is based, and I believe the work it can do will be helpful to the industry.

In the olden days the craftsman, anxious to know all that he might of his trade, rounded out his apprenticeship with a wander year—a period of checking up his knowledge, and adding to it, by seeing what others in his line were doing. Society now rather frowns on the wanderer but the wander year served a good purpose, and the Bureau seems to me to offer an up-to-date, efficient substitute for it to the earnest and ambitious rolling-mill man who desires to perfect himself in his work.

In the proportion that such men are represented in any industry, so will the industry forge ahead, or remain stationary, or fall behind. A Schwab represents a happy confluence of many forces—driving power, imagination, courage. As Lord Fisher is to the English navy, so is Schwab to the American steel industry. But the industry cannot depend on repetitions of Schwab; it must be continued and improved by the thousands of men who direct its operations from day to day, and, as I see it, the Bureau would offer to those men a means whereby they could make themselves more capable. To the owner of a plant, anxious to give some bright young man in his organization an opportunity to increase his knowledge of the business, or to solve some knotty rolling problem, the Bureau seems to me to be "made to order."

When Mr. Skinkle first approached me on this subject, I wrote him as follows:

"I sincerely hope you will be able to interest enough concerns in the proposition to justify proceeding with the work. It seems to me that if through your investigations any improvement in present methods can be found (and it seems reasonable to assume that you ought to be able to add something to our knowledge) the expense, considering the enormous tonnage of steel rolled in the United States will be fully justified. I do not venture to hope for much because after all the tonnage records of our mills

*Vice-President, American Car & Foundry Co., New York.

could not be made without good practice, but the driving to capacity necessarily precludes experimentation and this as I see it is precisely the field in which you will have the time to work unhurriedly; and I assume also to carefully analyze and to give the members the benefit of any new ideas that may be published in foreign technical journals (not generally accessible) concerning the industry."

I offer to the Society my apologies for intruding into a technical discussion these general remarks; perhaps I might not have taken the liberty had not the "Western Pennsylvania" in your title brought back so many boyish recollections, for I, too, am a Pittsburgher; and, so, rightful heir to my interest in the steel business.

Mr. S. N. Holstein:* It has given me great pleasure to read over these papers, but I realize the utter impossibility of an intelligent discussion of them within the short time available.

From many years experience operating mills, I can very heartily subscribe to the sentiment that there is needed a great deal of scientific study and analysis, and it would be of much benefit to the rolling-mill industry as the application of the principles developed would be very profitable.

Prof. Trinks's statements in many cases confirm observations of my own in mill practice, and the careful study of all the points involved by means of the experimental mill proposed by Mr. Skinkle, will no doubt assist in the discovery of the fundamental laws of rolling-mill practice, instead of the conglomeration of divergent theories of many casual observers.

During the past ten years there has been demanded from the steel industry increasingly higher standards of products, which has been accomplished only after many trials of various expedients known to the practical mill man, but with practically no known laws to guide him.

With laws scientifically established, a marked improvement in the quality of the steel itself may be naturally expected, but with the demand for better surfaces of materials, these studies are the only real means of accomplishment.

*Superintendent, Blooming and Bar Mills, American Rolling Mill Co., Middletown, O.

MINE-HOISTING DUTY CYCLES IN PRACTICAL OPERATION

By M. A. Whiting*

INTRODUCTION

In many classes of motor applications, the proper types and capacities of motors are determined most suitably by comparison with similar, and in many cases duplicate, drives. In mine hoisting, however, the form and depth of the mineral deposit, the daily output desired, the arrangements of the shaft bottom and tipple, underground haulage conditions, and various other factors all affect the hoist duty, so that it is the exception to find two hoists having substantially duplicate hoisting conditions. In one list of installations comprising 217 equipments of 200 horse-power and larger, of 99 different motor ratings, the only duplicate hoisting conditions are two groups each of five identical units, one group of three, and six groups of two each. In all but one of these cases the openings having duplicate hoisting conditions are located on the same property..

It is therefore necessary in nearly every case to calculate a duty cycle based on the data for the proposed hoisting operation. If the conditions are known, the duty cycle can be predetermined more closely than for almost any other complex operating condition. The duty consists principally of accelerating and retarding masses and hoisting and lowering weights, both of which can be calculated definitely in accordance with the fundamental laws of physics. The principal variable element, the friction, is fortunately a minor percentage so that even a considerable percentage of error in assumed friction will affect the total result only slightly.

The following conclusions can be drawn from a properly calculated duty cycle:

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1. Whether the project, as proposed, is practicable; that is, whether the desired number of trips per hour can be made for the depth, load, cage weights, caging time and other determining conditions.

2. Whether changes in drum shape or other mechanical features are necessary or desirable.

3. Type and capacity of drive, whether direct current or induction motor; continuous and momentary capacity of motor; in a direct-current Ward-Leonard equipment, the capacity of generator and its driving motor; in a fly-wheel set, the capacity of fly-wheel required for a stated degree of equalization of input.

4. Details and special features required—for example, if an extremely short acceleration period is used with an induction motor a liquid rheostat will not be fast enough.

5. Ease of operation; that is, whether the operator can meet the cycle to all practical purposes, and whether the wear and tear will be reasonable, or excessive.

6. Energy consumption and input peaks.

From time to time, a number of papers have been published covering methods of calculating duty cycles, and the selection of drum shapes. This paper will not take up these topics but will consider a hoist equipment which has been installed to operate under certain conditions but which may actually be operated in any one of several different ways.

DIFFERENCES BETWEEN CALCULATIONS AND PRACTICE

In actual operation the duty cycles may differ from the calculated duty cycles in a number of different respects, most of which fall under the following heads:

1. Small differences will occur due to the manner of functioning of the electrical apparatus. For example, where an ordinary calculated diagram shows, during acceleration and retardation, a uniform input or an input varying in a certain manner, the operation of the control equipment does not cause the input to vary at just this rate.

2. Small differences will occur due to differences between the actual and the assumed mechanical conditions. For example,

in hoisting a long trip of cars up a slope of varying grade, the duty cycle is commonly drawn as if the load passed abruptly from one grade to the next; whereas, actually, the transference is gradual.

As the purpose of the calculated cycle is to insure the application of the proper drive, all differences under the two headings immediately preceding are immaterial so long as their effects are negligible. The engineer who works up the requirements should be able to determine whether any of these effects may be large enough to affect the result, and, if so, he should modify accordingly his deductions from the original calculated cycle.

3. Differences, often of importance, occur by reason of the load varying from the assumed data—not only a change in material per trip, but changes in mass of drums and cages to be accelerated.

4. Differences, often of importance, occur because the time available for hoisting is greater or less than originally given. This difference in time available for hoisting may arise from a difference in time required for caging or from a difference in the required number of trips per hour.

5. In some cases, even where the conditions to be met are as favorable as the original conditions, the operator may handle the hoist with poor judgment and obtain poor results, either from indifference, or because the best method of operation has not been impressed on him.

The subject is very extensive and cannot be covered completely in a paper of reasonable length. A few of the most important cases are discussed herein.

The majority of the differences between assumed and actual conditions have their effect principally during the accelerating and retarding periods. In an induction-motor hoist, approximately one-half the electrical energy drawn from the incoming line during acceleration is wasted in the resistor, and ordinarily one-half or more than half of the energy drawn from the line during retardation is similarly wasted. Partly on this account, differences between assumed and actual operating conditions are of greater importance in an induction-motor hoist than in a direct-current hoist with Ward-Leonard control.

EXAMPLE SELECTED FOR COMPARISON

The example chosen is one which is near the limit for which an induction-motor is physically practicable, but for which in many cases an induction-motor would be the proper selection. (Under some conditions of power supply this case would require a direct-current hoist with fly-wheel equalization.)

Weight of coal per trip	4500	pounds
Weight of car	3000	pounds
Weight of cage	9000	pounds
Rope	1.25	inches
Vertical shaft, lift	245	feet
Trips per minute	2.5	
Trips per hour	150	
Time required for caging and dumping	5	seconds

Balanced operation only. Equalization of input not necessary.

To meet these conditions the following details have been selected:

Accelerate 6 seconds, run 7 seconds, retard 6 seconds, rest 5 seconds. Drums cylindro-conical.

Four turns (plus holding turns)	at six-foot diameter
Four turns	on cone
Four turns	at seven-foot diameter
Assume drums 180,000 pound feet, squared	
Assume eight-foot head sheaves, each	2700 pounds
Assume mechanical efficiency	80 per cent.
Rope speed, at full speed of motor, on small cylinder	1045 feet per minute
Rope speed, at full speed of motor, on large cylinder	1220 feet per minute

This drum shape and the assumed values for acceleration, etc., may not be exactly the best to meet the stated hoisting requirements but are approximately the best. For conditions of this kind a number of different drum shapes may be found differing to some extent but providing nearly identical overall results.

ORIGINAL CALCULATED CYCLE

Fig. 1 shows the theoretical cycle in accordance with the foregoing data. The combined static effort—that is, total effort except

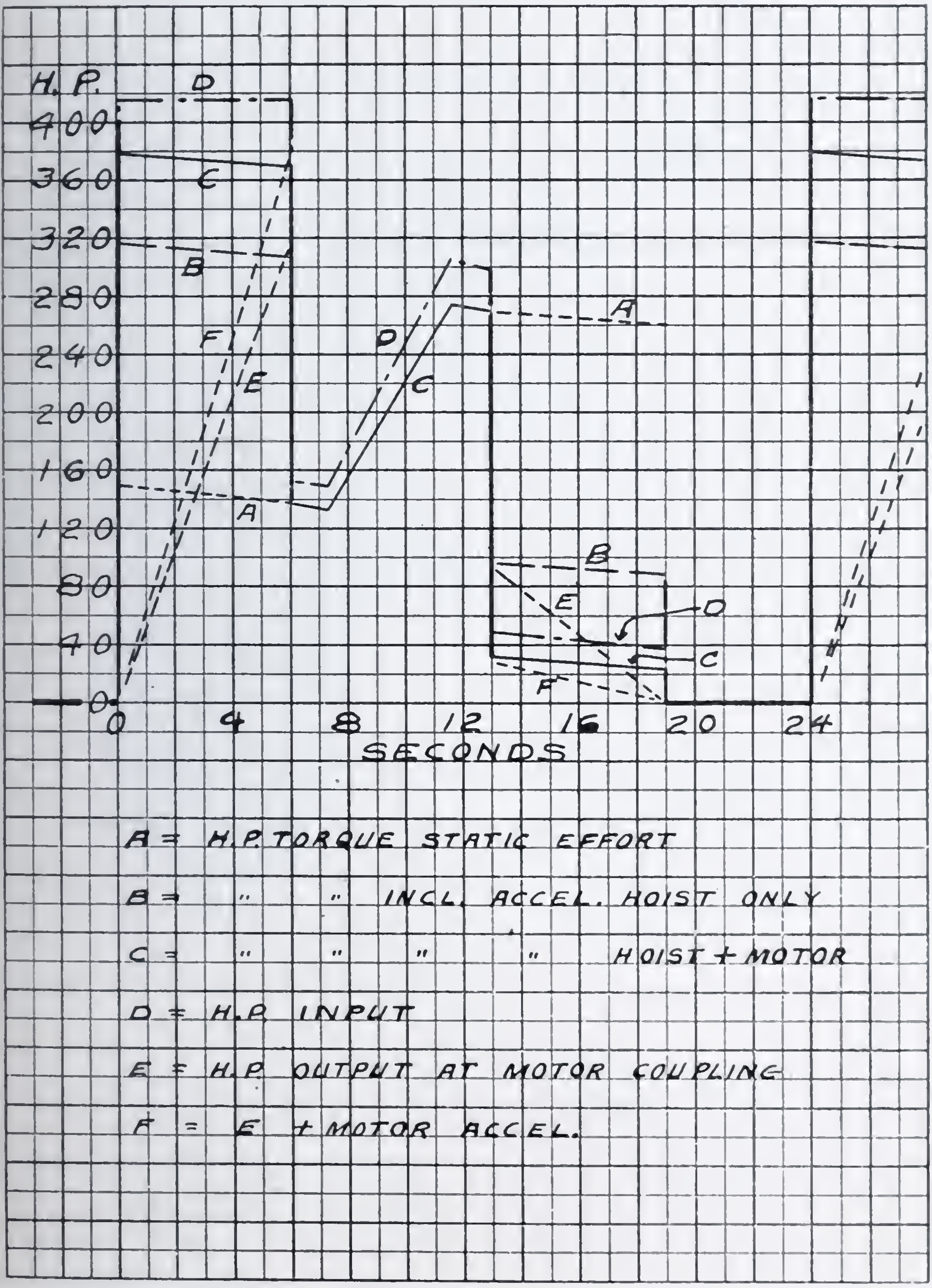

Fig. 1.

acceleration—is shown by dotted line *A*, solid line *C*, dotted line *A*. The efforts for accelerating and retarding all parts except the motor were calculated for a uniform rate of acceleration. Adding these to the static effort during acceleration and deducting during retardation, the total effort except motor acceleration is shown by *BCB*.

Using the standard 16-pole, 300-horse-power, 450-r.p.m., 2200-volt motor, and adding for its rotor acceleration, the root-mean-square of the cycle—that is, the continuous load which will give approximately the same heating effect—is 285 horse-power. As the maximum torque requirements, both for the duty cycle and for purposes of construction and maintenance, are also within its capacity, the 300-horse-power motor mentioned is suitable. Having selected the motor, the duty cycle can be completed by adding to the diagram the effort for accelerating its rotor, and deducting similarly for retarding its rotor. The total diagram, including the effect of the motor rotor, is shown by line *CCC*.

All the efforts referred to in the foregoing are plotted in Fig. 1 as "horse-power torque"—that is, as torque expressed in terms of the horse-power output to which these torques are equal at full speed. Inclined lines, *E*, show the actual or "brake" horse-power output at motor coupling during acceleration and retardation. Inclined lines, *F*, show the actual horse-power output including armature acceleration and retardation.

The motor efficiency is practically 90 per cent. throughout, except during the very light load while retarding; for the latter condition, a no load loss of five per cent. of rating is assumed. This determines the input from the power system, shown by line *D*—plotted in horse-power to compare readily with the output diagram.

Summary for the original cycle:

Root-mean-square 285 horse-power. Input per trip 4325 horse-power seconds = 0.90 kilowatt-hour.

Electrical efficiency of cycle, 58 per cent.

Overall efficiency of cycle at 80 per cent. mechanical efficiency, 46 per cent.

The deviations encountered in actual practice can best be studied and compared with the original cycle by means of calculated cycles, which may serve engineers in charge of operation as a general guide in studying the possibility of improving the operation of actual installations.

CASE 1. APPLICATION OF CALCULATED CYCLE TO PRACTICE

The hoist we are considering will naturally be controlled by a magnetic control rather than by a liquid rheostat. The standard equipment has an eight-point acceleration, and its speed-torque characteristics are approximately as in Fig. 2.

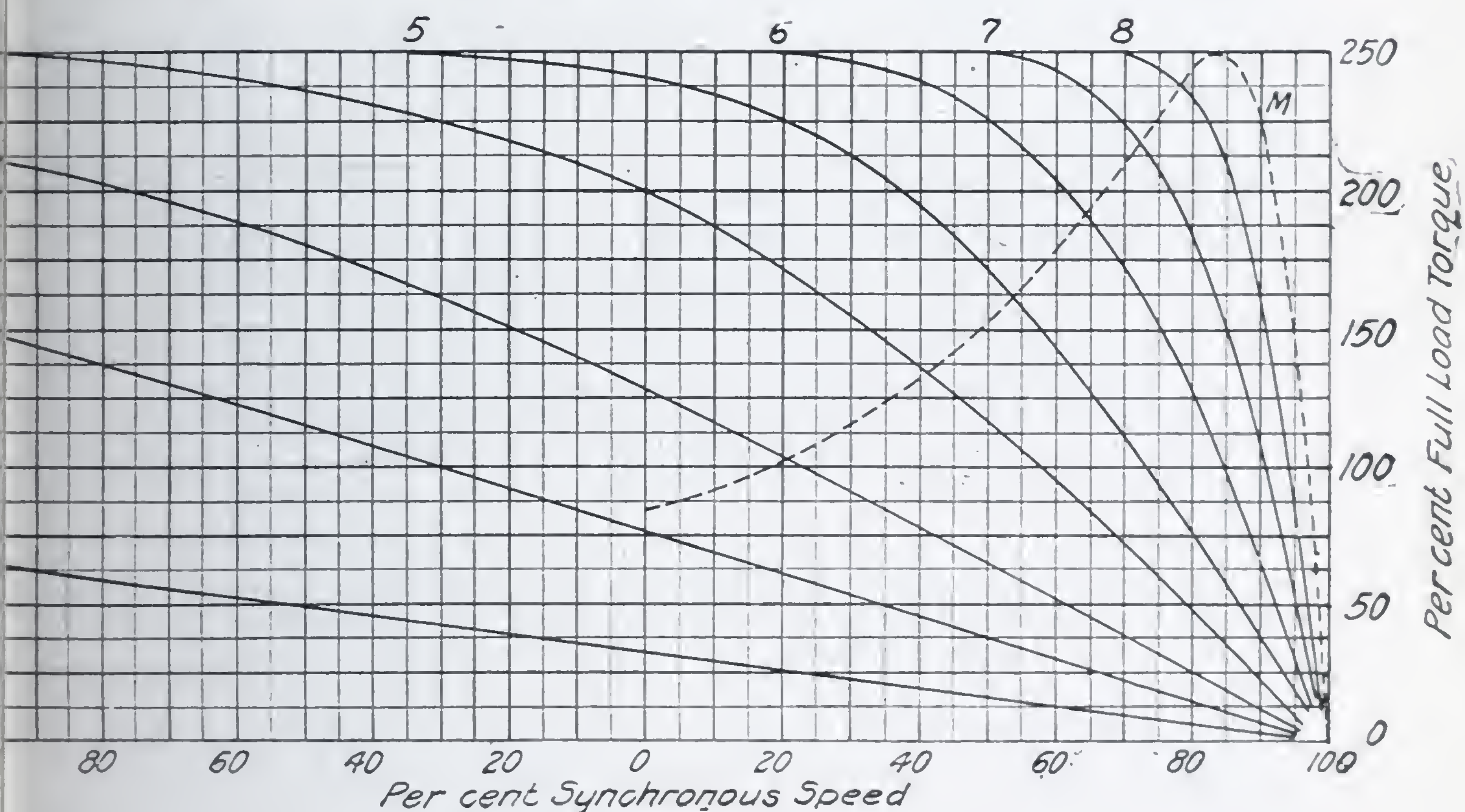

Fig. 2.

Fig. 3 shows approximately how an actual duty cycle will look when operating substantially in accordance with the original duty cycle. In order to develop an average accelerating torque equal to 379–369 horse-power as required by Fig. 1, the current limit relay settings have been adjusted to notch up at 300 horsepower. The trip is started by throwing the master controller to full-speed position. Since at a standstill, the current inrush on the second point is less than the setting of the relays, the third

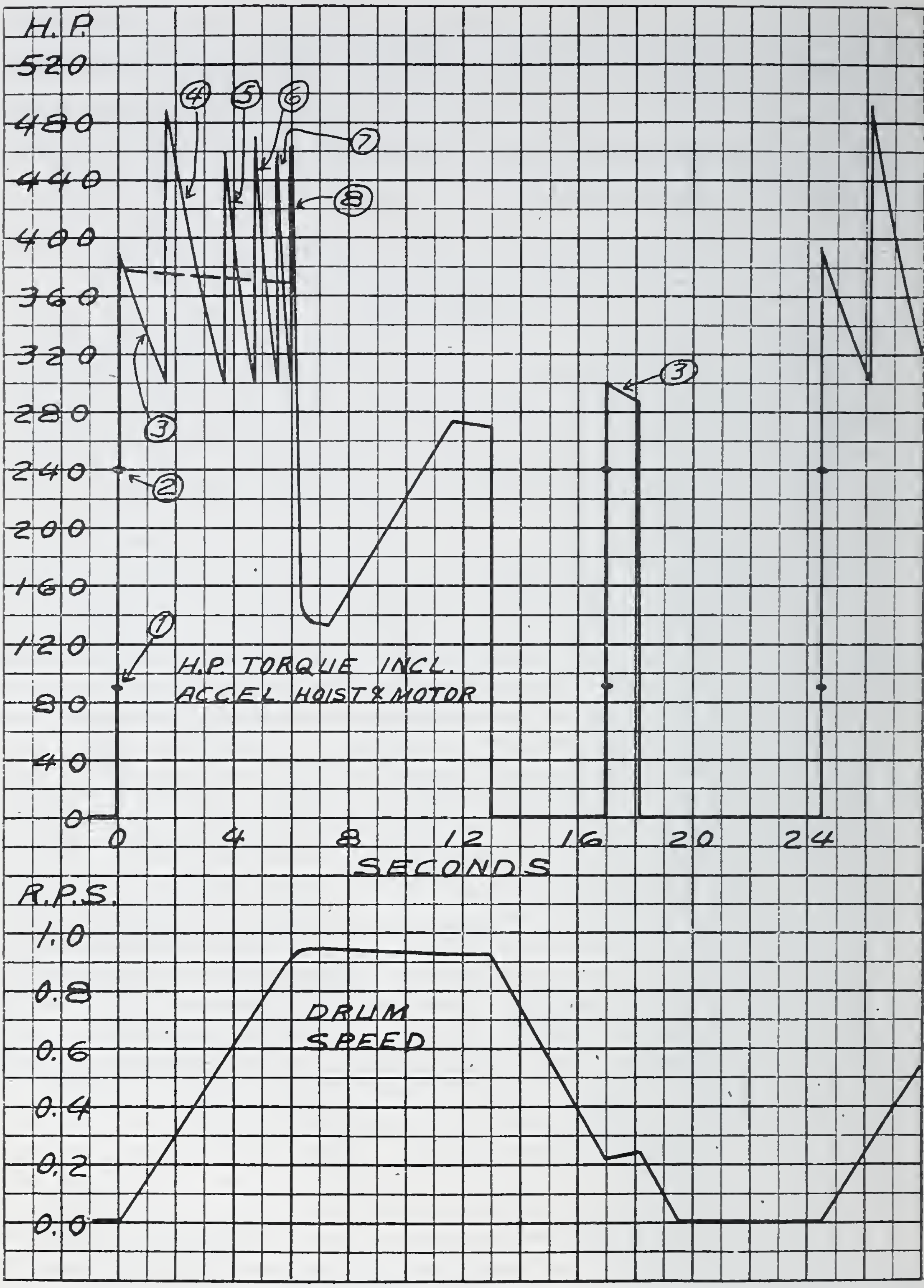

Fig. 3.

point—the second resistance contactor—closes immediately and the acceleration proceeds on the various points as shown by the correspondingly numbered parts of the horse-power curve. Since the torque available for acceleration fluctuates, the rate of accel-

eration is not strictly uniform. In this case, however, the minimum is so high a percentage of the average that the effect on the rate of acceleration is negligible.

The curve of drum speed in Fig. 3 shows a maximum of 0.945 r.p.s. instead of the rated speed of 0.923 r.p.s. This is because the motor load during full-speed running is less than the rated load.

In Fig 3, the operator begins to retard at 13 seconds—as in the theoretical cycle—by cutting off power, and coasting. After four seconds of coasting, when the hoist has dropped to about 25 per cent. speed, he realizes that he will fall short, throws on his controller to the third point, cuts off again and coasts in. If he holds the power on for 1.1 seconds the hoist will then just coast in to the mark in 1.4 seconds additional.

Summary for case 1:

Root-mean-square 296 horse-power. Input per trip 4432 horse-power seconds = 0.92 kilowatt-hour.
Input 2.5 per cent. higher than for original cycle.
Time per trip 0.5 seconds longer than for original cycle.
Possible trips per hour two per cent. less than for original cycle.

CASE 2. COAST TO REST TOO SOON AND REQUIRED TO RE-START

To show how the skill of the operator in retarding affects the operation the following case will be of interest. It represents the work of an operator who is either over cautious, new on the job, or improperly trained. Refer to Fig. 3 as far as 13 seconds only. Assume that the operator cuts off power at 13 seconds, coasts to rest before realizing that the trip is not coming in, and then throws on his controller to pick up enough speed to coast in.

The hoist coasts to rest in 5.25 seconds and stops, 0.26 of a revolution short of the mark, with the loaded cage 5.75 feet short of the dumping position. The operator then jogs the hoist by throwing the controller over several points, but the current limit system prevents the contactors from closing beyond the third point.

The inrush is 390 horse-power, which drops to about 330 horse-power during the jog. Assuming that this time the operator's judgment is correct, he cuts off after 2.4 seconds at 0.16 r.p.s. and coasts in to the mark in 0.9 seconds more.

Summary for case 2:

Root-mean-square 306 horse-power. Input per trip 5016 horse-power seconds = 1.04 kilowatt-hours.
Input 16 per cent. higher than for original cycle.
Time per trip 2.55 seconds longer than for original cycle.
Possible trips per hour 9.5 per cent. less than for original cycle.

The considerably increased input required for this case may occasion surprise. It is accounted for by the fact that the power used to finish the trip is applied between zero and 17 per cent. of full speed. The electrical efficiency during this period, motor and resistor losses included, is, therefore, only eight per cent. and since the ascending rope is on the large cylinder the torque required is high.

The author once witnessed a striking example of operation somewhat along the line of case 2, but much worse. In a very large induction-motor water hoist the overwind and overspeed device—of the governor type—had originally been set to work too soon, so that, unless the operator retarded unreasonably early in the trip, the hoist would be stopped short by this device. After it was properly adjusted, the operator continued to retard too early. To make it worse, instead of holding his controller on a very low torque point, or jogging on and off, he brought his controller only a little more than half way back and slowed down by dragging the hoist brake heavily. In finishing the trip the motor crawled along for 10 to 15 seconds at about 50 per cent. overload and below one-quarter speed. The waste of energy was, of course, very great, with nothing to show for it except larger power bills, increased wear and tear on apparatus and a slower rate of unwatering a flooded level.

CASE 3. CUT OFF AT EXACT POINT FROM WHICH THE TRIP WILL COAST IN

The ideal operation is obtained by cutting off at a point from which the hoist will just coast in to the mark. Thus there are no partial-speed rheostatic losses except while accelerating, and the entire stored energy of the moving system is utilized in finishing the lift, so that the energy consumption is a minimum. Obviously, the wear and tear on equipment is least by this method.

To meet this condition exactly, the hoist is run at full speed 0.375 seconds longer than in the original cycle, is cut off at 13.375 seconds, and takes 5.25 seconds more to coast in.

Summary for case 3:

Root-mean-square 284 horse-power. Input per trip 4183 horse-power seconds = 1.16 kilowatt-hours.
Input 3.3 per cent. lower than for original cycle.
Time per trip 0.375 seconds shorter than for original cycle.
Possible trips per hour, 1.5 per cent. more than for original cycle.

It is evident that even a good operator cannot cut off as accurately as this, but if the loads are substantially constant he can cut off at a depth indicator mark from which, on the average, the hoist will somewhat more than coast in. The final stop is then made easily by applying the brake at a low speed. Thus the ideal cycle, coasting to rest, is very nearly realized; since the brake is applied only at a low speed the percentage of the stored energy wasted by the brake is very low and will not materially increase the energy consumption over the ideal cycle.

GOOD AVERAGE OPERATION, CASES 1 AND 3

A good man should be capable of learning by himself, or at least should be capable of being taught to operate much better than in case 2. Since loads vary somewhat, and the operator's time of reaction will sometimes vary a fraction of a second, a good operator will bring in some of his trips by coasting in exactly; he will come in with a little to spare and use the brake slightly to

stop many of his trips; he will tend to stop short and will put on power again to bring in a few trips. The average performance will approach closely to the ideal.

CASE 4. PLUGGING TO SHORTEN RETARDATION

If necessary to gain about one second per trip to keep ahead of the cars on the bottom, the method most directly available to the operator is to run later at full speed and "plug" the motor or use the brake to make a quick retardation. Assuming a uniform rate of retardation in each case, for each second by which the retardation is shortened the full speed running time must be increased 0.5 second to cover the required distance, so that the time saved per trip is one-half the time by which the retardation is shortened.

Fig. 4 shows a cycle identical with the original cycle (Fig. 1) except that full speed is held one second later and the hoist is retarded to rest in four seconds. The input necessary to develop the required plugging torque is shown in Fig. 4 by line *D*, between 14 and 18 seconds.

In plugging, only part of the stored energy of the hoist is utilized in finishing the lift, and the balance is wasted in the resistor. In Fig. 4, the triangle of energy contained between the sloping line, *F*, and the zero line from 14 to 12 seconds is wasted in the resistor. Likewise, the input while plugging, between line *D* and the zero line, is wasted—chiefly in the resistor but partly in motor losses.

Summary for case 4:

- Root-mean-square 296 horse-power. Input per trip 4788 horse-power seconds = 0.99 kilowatt-hour.
- Input 10 per cent. higher than for original cycle.
- Time per trip one second shorter than for original cycle.
- Possible trips per hour four per cent. more than for original cycle.

CASE 5. HOIST BRAKE USED TO SHORTEN RETARDATION

The same speed-time cycle as in case 4 may be obtained by using the hoist brake in place of plugging. In this case the plotted cycle will be the same as Fig. 4 except that the input,

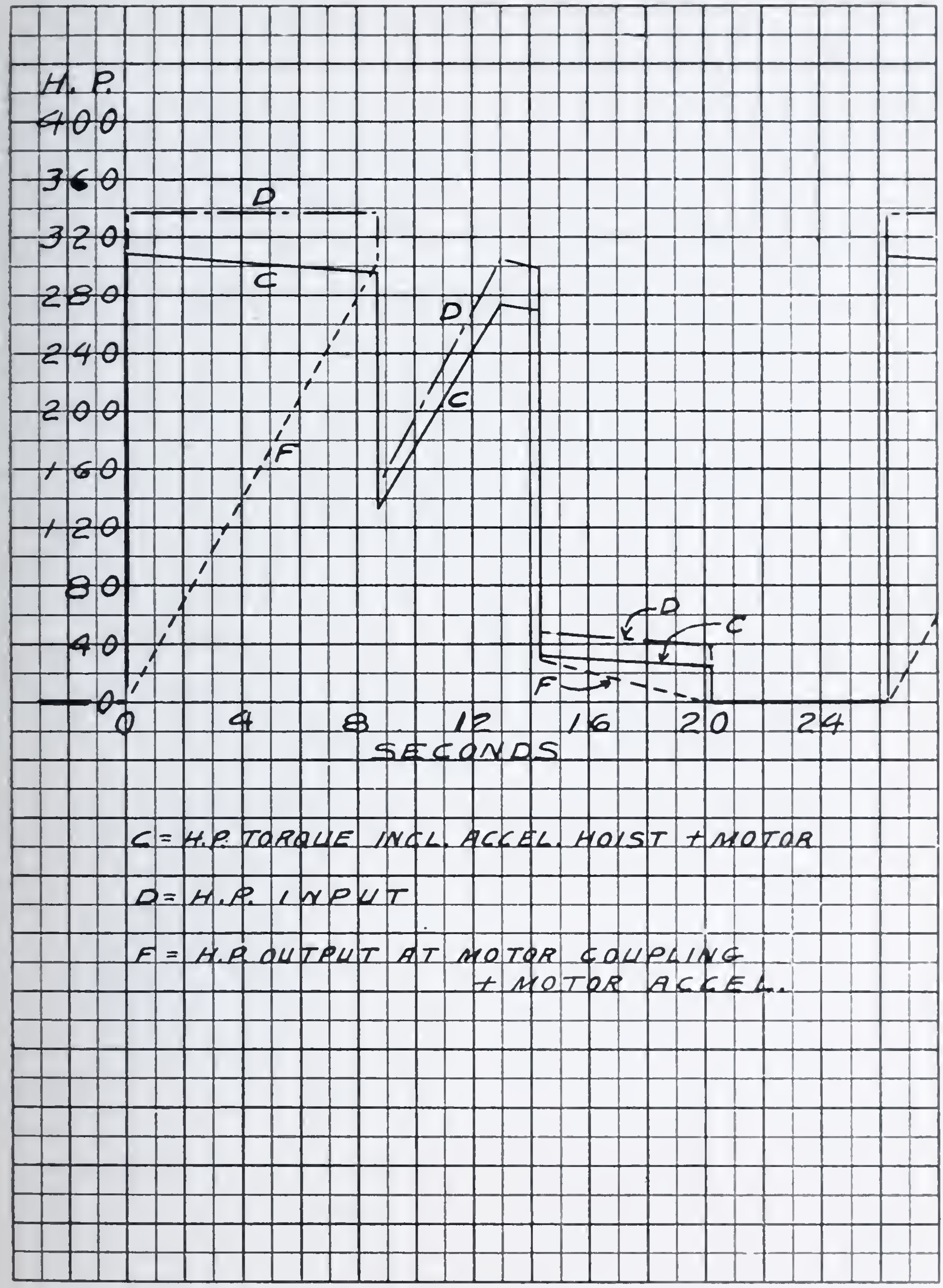

Fig. 4.

line *D*, will be zero between 14 and 18 seconds. Part of the stored energy of the hoist, the triangle between the inclined line, *F*, and the zero line from 14 to 18 seconds—which in the plugging cycle was wasted in the resistor—will be wasted in the brake.

This cycle is evidently more economical of power than the corresponding plugging cycle under case 4.

Summary for case 5:

Root-mean-square 292 horse-power. Input per trip 4368 horse-power seconds = 0.905 kilowatt-hour.

Input one per cent. higher than for original cycle.

Time per trip one second shorter than for original cycle.

Possible trips per hour four per cent. more than for original cycle.

CASE 6. FASTER RATE OF ACCELERATION

If the power system will take the peak, it will be possible to save one second by a faster acceleration instead of by a faster retardation as in case 4. This will impose a peak of 545 horse-power, plus fluctuations due to contactors closing. Assuming a retardation in six seconds, as originally, the summary for the case is as follows:

Root-mean-square 302 horse-power. Input per trip 4177 horse-power seconds = 0.87 kilowatt-hour.

Input 3.4 per cent. lower than for original cycle.

Time per trip one second shorter than for original cycle.

Possible trips per hour four per cent. more than for original cycle.

CASE 7. INCREASED TIME TO ACCELERATE

Fig. 5 shows a cycle like the original cycle except for a slower rate of acceleration occupying 8.7 seconds and ending at the beginning of the cone. The retardation is assumed to begin at the same point in the trip as in the original cycle, retarding in six seconds. A condition such as this may result from the operator moving the controller over too slowly, or from too low a setting of current limit relays. Low voltage has the same effect as too low a setting of the current limit relays.

Summary for case 7:

Root-mean-square 275 horse-power. Input per trip 4535 horse-power seconds = 0.94 kilowatt-hour.

Input 4.8 per cent. higher than for original cycle.

Time per trip 1.3 seconds longer than for original cycle.

Possible trips per hour five per cent. less than for original cycle.

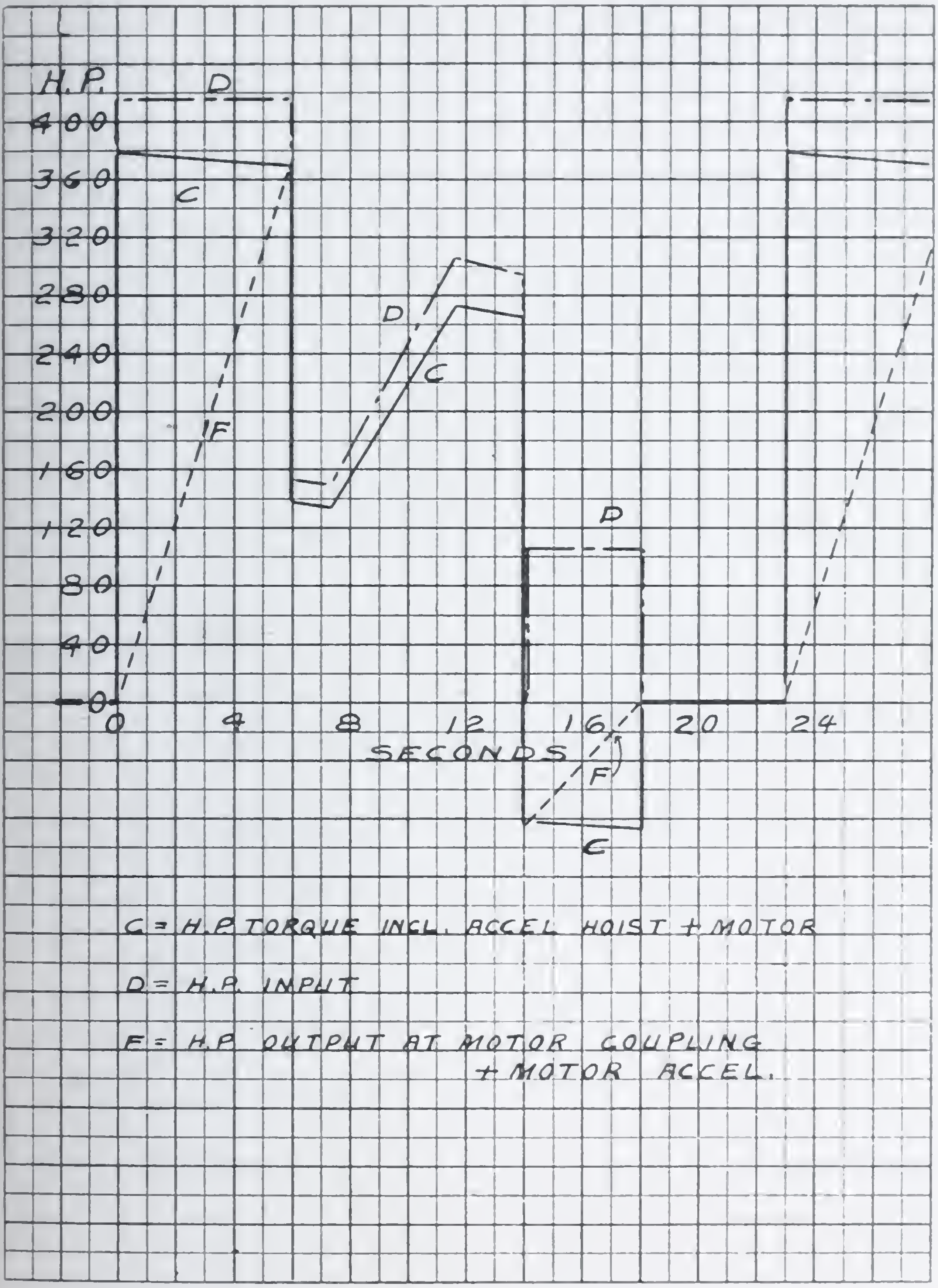

Fig. 5.

Observe that the root-mean-square for case 7 is less than for the original cycle. This is by no means always true for an increased time of acceleration. In an installation in which the static effort during the accelerating period is itself considerably

greater than the continuous motor capacity, the lengthening of the accelerating period will increase, instead of decreasing, the root-mean-square.

In a hoist installation of a given design an increased time of acceleration always increases the energy consumption. This will be evident from the following. The work during acceleration consists of two elements, one of which, the acceleration of the mass, is, generally speaking, a constant quantity and is accomplished at one-half the full-speed efficiency of the motor; that is, at approximately 45 per cent. electrical efficiency averaged throughout the acceleration. The other element, the hoisting of the load against gravity during the accelerating period, is likewise accomplished at an average electrical efficiency of about 45 per cent., but the distance hoisted at this low average electrical efficiency increases with an increase in the time of acceleration.

It follows therefore that for the lowest conceivable energy consumption per trip the acceleration period should be reduced to practically zero. In any ordinary case this would increase the momentary accelerating peak so greatly as to require an excessively large motor to develop the accelerating torque, and would impose a prohibitive load on the transmission line. A further limitation is imposed by the necessity of keeping within reason the shocks and stresses on ropes and cages.

CASE 8. TIME OF ACCELERATION ENTIRELY TOO LONG

Fig. 6 shows a cycle in which the acceleration occupies 14 seconds, assumed to be at a constant rate in r.p.s. per second. Beyond this point the operation is assumed to follow the original cycle. This extremely slow acceleration is entirely unreasonable but some men, when a hoist is not busy, may operate in this fashion under the mistaken impression that they are favoring the electrical equipment. The acceleration is not completed until the ascending rope has wound 2.4 turns on the cone and the descending rope has unwound 2.4 turns from the other cone. Since the static torque increases—on account of the drum shape—before the resistor is all cut out, this causes an additional element of energy loss.

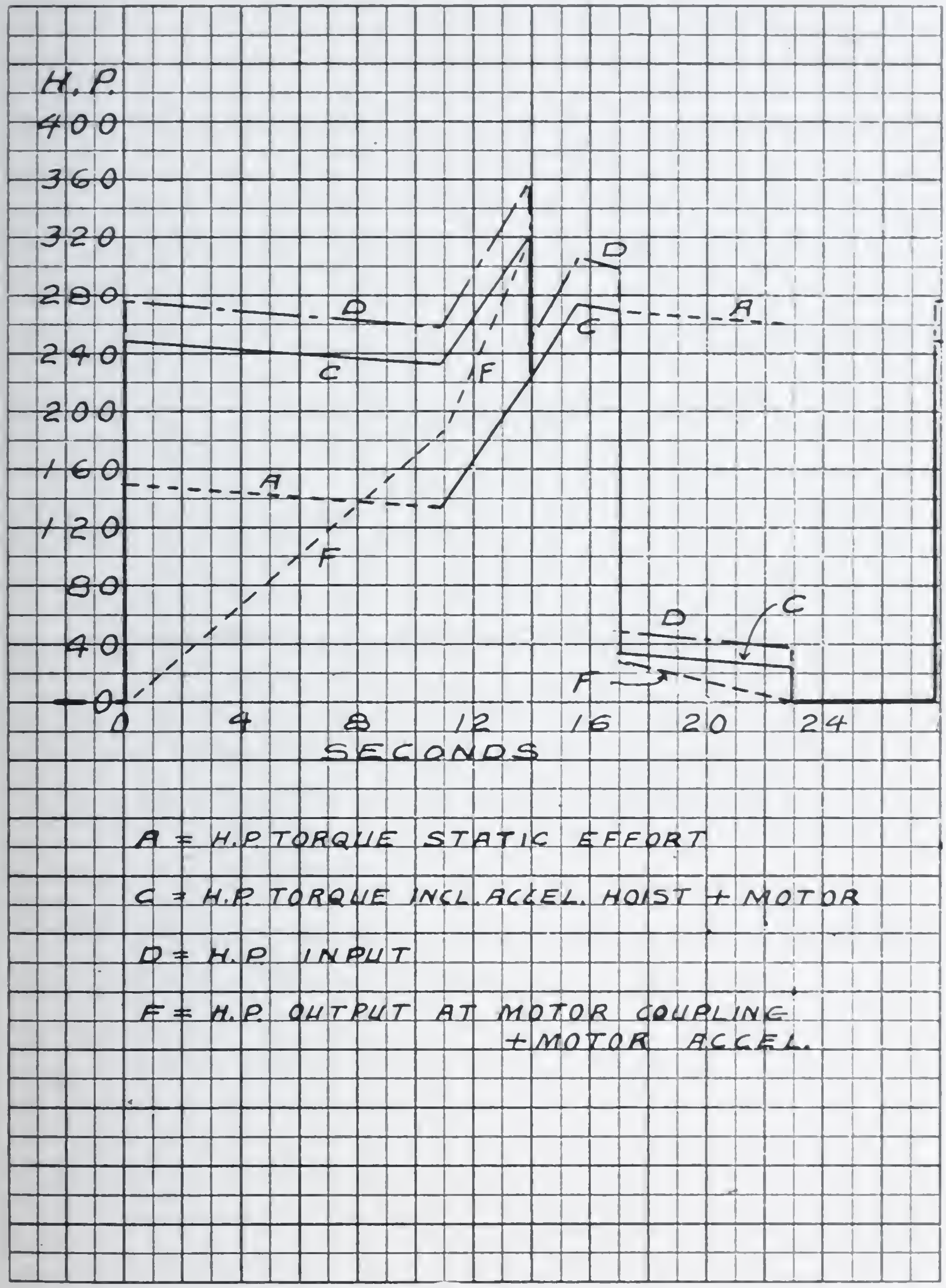

Fig. 6.

Summary for case 8:

Root-mean-square 276 horse-power. Input per trip 4950 horse-power seconds = 1.02 kilowatt-hours.

Input 14.5 per cent. higher than for original cycle.

Time per trip 3.9 seconds longer than for original cycle.

Possible trips per hour 14 per cent. less than for original cycle.

CASE 9. CURRENT LIMIT RELAYS SET ENTIRELY TOO LOW

This case illustrates a condition which cannot ordinarily arise except in a conical or cylindro-conical drum hoist with magnetic control. Fig. 6, discussed under case 8, shows a cycle of which an approximate equivalent might be obtained with a magnetic control if the current limit relays were set high enough but the operator notched up his master controller too slowly; or, with a liquid rheostat control, which has a time limit acceleration, approximately the equivalent of Fig. 6 might be obtained.

Assume, however, a magnetic control equipment in which the current limit relays are set so low as to cut out at 180 horse-power, thus maintaining an average total effort of 240 horse-power while accelerating. The effect is shown approximately in Fig. 7. While the ropes are winding on the cylinders, the relay settings do not prevent the acceleration of the hoist (at about one-half the normal rate for the original cycle); but while accelerating on the fourth point the ropes start up and down their respective cones, so that the static effort (the dotted line) increases. The margin of torque available for acceleration drops so rapidly that the acceleration practically stops at 13 seconds.

If the operator lets the hoist run in this manner on the fourth point, the further increase of load—due to the cones—will cause the motor to slow down because it is running on resistance, approximately as shown by the lower branch of the speed curve. But a maximum torque push-button is usually provided—primarily for other purposes—by which the operator may close the contactor for the fifth point irrespective of the current limit. If the operator uses this push-button as soon as the speed becomes constant on the fourth point, the effect of the fifth point will be about sufficient to meet the increased load due to the drum shape. and beyond the cones the hoist will run at about 80 per cent. of normal speed.

The cycle is not shown carried to completion as the calculations can be made only by the "cut and try" method and are quite laborious, but it is evident that the loss of time and the increase in energy consumption are very considerable.

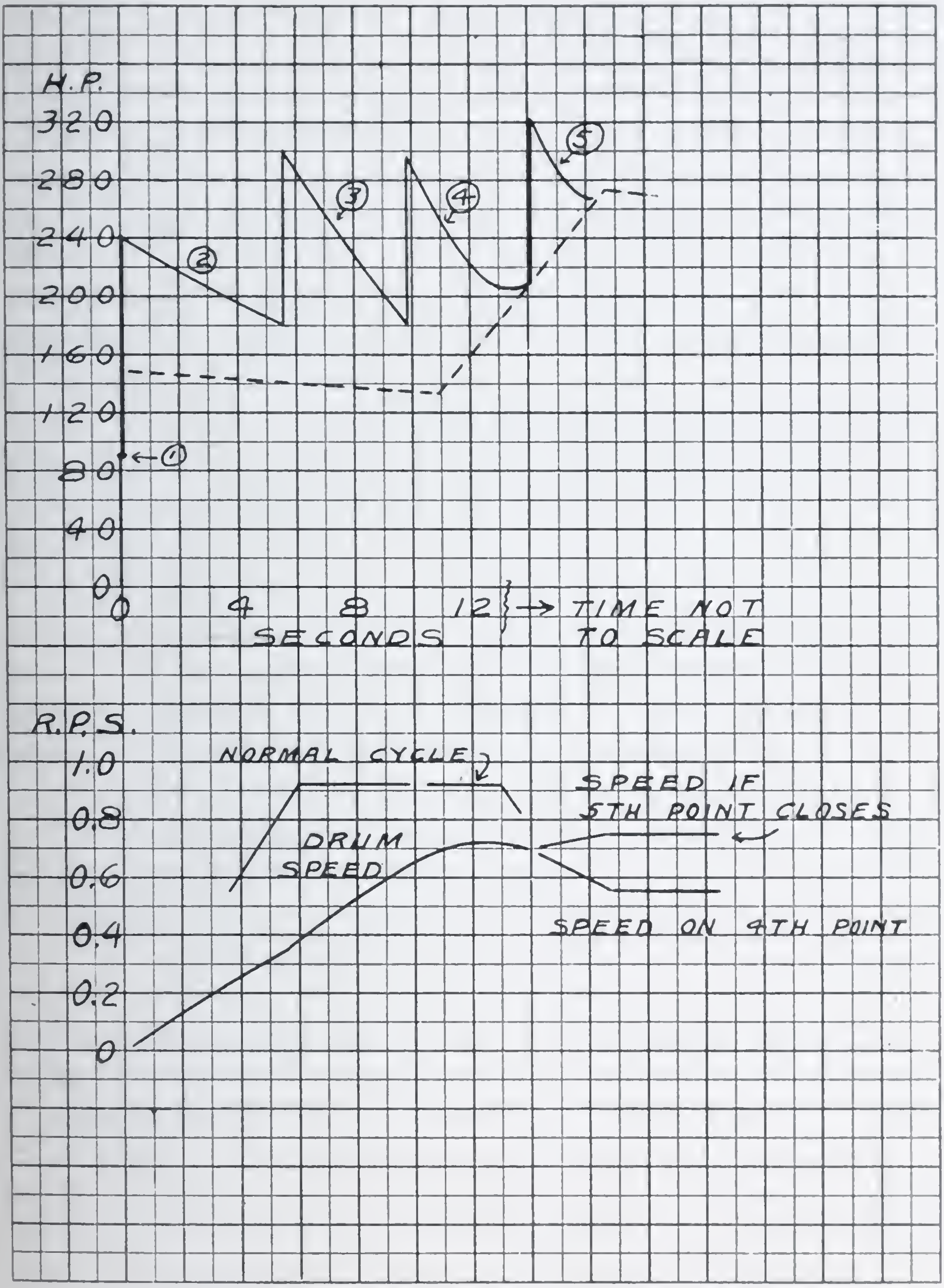

Fig. 7.

MISCELLANEOUS DEVIATIONS FROM ORIGINAL CONDITIONS

Change in Rest Period. If the rates of acceleration and retardation are unchanged, the change of time at rest will, of course.

change the number of trips per hour, will not change appreciably the energy consumption per trip, but will have a slight effect on the motor heating. Following the approximate rule that an induction-motor at rest dissipates its heat at only one quarter of the normal rate, if the rest period in the original cycle (Fig. 1) could be reduced to zero the root-mean-square would be increased five per cent.

Low Voltage. If the reduction in voltage is approximately constant and not extreme, so that it is possible (after changing the current limit settings) to obtain the requisite accelerating torque and accelerate in the normal time, the efficiency will be only slightly affected and the time of trip will not be appreciably affected. But, if the voltage reduction is extreme, or if the relays are not set for the reduced voltage, the time of acceleration will be considerably increased, and efficiency and production reduced accordingly. An extreme reduction of voltage will increase the motor heating about as in ordinary applications.

Increased Mass of System. If drums or cages are considerably heavier than in the original data, this may be met during acceleration by increasing either the time or the horse-power peak, either of which decreases the efficiency; it may be met during retardation, either by increasing the time to permit coasting in—thus avoiding further decrease of efficiency—or by plugging or braking, which further decreases the efficiency.

GENERAL SUMMARY

The following general principles may be laid down. Some of them are contained in the various illustrative cases, while most of the others are based on an extension of the same reasoning.

As far as practicable the power of the motor—except when plugging—should be used at full speed; that is, as much of the hoisting work as practicable should be done with the resistor cut out.

The ideal cycle has a short period of acceleration—limited by the effect of the peak and the operation of the cages, etc.—and is cut off at a point from which the trip will just coast in.

Where, for any reason, it is necessary to retard at a higher rate than the natural coasting rate, the power required during retardation should be used at as high a speed as is practicable, to avoid unnecessary resistor losses and loss of time.

Where not unsafe, it is best to coast in to approach the mark with a little speed to spare. This can be checked with slight loss by plugging or braking at the very end of the trip.

For a fast retardation, the energy consumption and motor heating are less for retardation by the hoist brake than for plugging. With a good electrical equipment and reliable power, plugging is considered more dependable than heavy braking.

When a hoist is not busy, the operator should accelerate at the normal rate, coast in as nearly as possible, and take the extra time in longer rest periods.

It needs to be impressed on some operators that in handling extra heavy loads, or in breaking in a new equipment, they are *not* making it easy for an induction-motor drive, by running at partial speed.

APPLICATION TO DIRECT-CURRENT HOISTS

The foregoing analysis applies particularly to induction-motor hoists. For the limited class of direct-current hoists, which are fed from an ordinary direct-current feeder and controlled by an ordinary armature resistance control, the same considerations apply almost without change.

For the typical direct-current hoist, with its own motor-generator set and Ward-Leonard control, these conclusions apply only in part. Since the acceleration and retardation are accomplished by voltage control—not by a resistor in the armature circuit—and since a rapid retardation regenerates energy which is returned to the motor-generator set, considerable variations in the time of acceleration or retardation introduce relatively small variations in losses.

DISCUSSION

Dr. John S. Unger:* This is a subject with which I am not very familiar, but I would like to ask some questions. What is the greatest depth of which you have any knowledge from which material is hoisted either by steam or electric motor, and is there any particular difference between steam and electric hoisting in the matter of speed?

Mr. Graham Bright:† I think Mr. Whiting should be congratulated on the paper he has presented to-night. It has been a very good sequel to the paper which was presented to the Pittsburgh Section of the American Institute of Electrical Engineers by Mr. F. L. Stone a year or so ago.‡ One point which Mr. Whiting brought up, and which will be appreciated by those who have had very much to do with hoisting, is in regard to the judgment of the operator. I suppose most of the large manufacturers have had the same complaint. After an equipment has been put in, the customer says it does not meet specifications, and does not give the anticipated output. We get on the job and find that this question of the judgment of the operator is the whole trouble.

This was brought to mind to-day on a visit I made to a mine in which they were supposed to make three trips a minute. With an experienced operator they have had no difficulty whatever in accomplishing this. The operator to-day had been on the job less than two weeks, and he was doing what Mr. Whiting showed in one of his cycles, only in a very much more exaggerated way—that is, cutting off too soon, putting on power, and creeping in to his dumping position with one or two notches of power. Instead of having power on a second or two, as shown in Mr. Whiting's cycle, he had it on from five to eight seconds. He was

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‡Drum shapes as affecting the mine hoist duty cycle and motor rating. Trans. A. I. E. E. 1918, v. 37, p. 1677-1695.

taking 200 amperes, and the full load of the motor was 165. You can see what that was doing not only to the heating but to the amount of power being used. If you want to obtain these high-speed cycles you must have an operator on the job who knows how to handle the hoist, and that can not be acquired in any short space of time. It takes a particular type of man to do it. Some operators never will learn. Others will acquire it in a fairly short time.

Most cycles shown do not require plugging. We frequently come into cycles, especially where large outputs are desired, where you simply can not get along without plugging. It is a nice thing to be able to slide into the dumping position without requiring power or brake, but in practice you can not always do it. Sometimes you have to use a cycle that requires very heavy plugging, entirely too much to handle by any brake system as it would burn up your brakes. The only way to handle it is to plug the motor. This not only takes a larger motor but considerably more energy in the power system and impairs your efficiency. A cycle of that kind would be handled easily by the Ward-Leonard system of control.

DR. JOHN S. UNGER: Do you not save money by doing that?

MR. GRAHAM BRIGHT: Yes, but you are getting on dangerous ground. If some little accident happens, you get into a wreck that will cost many times the difference between the Ward-Leonard system and the alternating-current system. Not only that, but the power companies penalize you heavily for the short-time peaks, because they have to supply capacity for those peaks. Under the conditions on which you buy your power, you are sometimes forced to go to the more expensive equipment using a fly-wheel. This is very much safer on these high-speed runs, because the operator has absolute control over his equipment at all times; which he does not have when using the alternating-current motor.

In regard to the shape of the drum. As Mr. Whiting says, in your calculations you might arrive at several different shapes and still have a pretty good drum. For short lifts, the cylindro-

conical drum shows advantages especially in cutting down the peak. There are other slower cycles where the peak does not cut so much figure, in which case the straight cylinder drum is really better. In the West, where they have to use two and three layers of rope on the drums, we have hoists running to 3800 feet in depth.

MR. ROBERT LINTON:* Is that hoisting from different levels?

MR. GRAHAM BRIGHT: Most all metal mines hoist from a variety of levels. North Butte is now mining at a depth of about 3000 to 3600 feet. They hoist 14,000 to 16,000 pounds of ore, with cylindrical drums using about three layers of cable.

DR. JOHN S. UNGER: Have they ever experimented with a cylindro-cycloidal drum?

MR. GRAHAM BRIGHT: Not that I know of. Those drums have theoretical advantages, but when you come down to practice the advantage is not there. Besides, that kind of drum is very difficult to make. In regard to the advantages of these freak shapes, as we sometimes call them, the advantages are sometimes more fanciful than real. You have to know the exact weight and the radius of gyration to tell what advantage you are getting over other drums and in some cases these determinations are rather difficult. I know of one case where we used a cylindro-conical drum and after putting it in operation the customer complained that the resistance got too hot. Everything checked up correctly in the calculations, but, we found the drum weight was double what was given us in the first place. That told the whole story. The drum weighed so much more than estimated that it simply kept the hoist working on the resistance considerably longer than contemplated, and, furthermore, it lengthened out the cycle. The customer was not getting his output. We happened to have enough margin in the motor to take care of it by putting in more resistance. In figuring out the advantage of one shape of drum over another there is always a question due to the fact that you can not tell exactly what your weights are going to

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be. The manufacturer that makes the drum may, on account of fear of cracks due to shrinkage strains, put in more material than was thought necessary by the man who figured it out.

In lengthening out the acceleration it was shown that the kilowatt-hours were increased but the root-mean-square was decreased. That is due to the fact that we increased the length of the cycle. If we keep the same total time of cycle, but lengthen out the accelerating period, it will increase the root-mean-square.

Mr. M. A. Whiting: I did not bring out the effect of lengthening the acceleration and changing the gearing to give the same time of trip, because I was dealing with the performance of a hoist after the design was fixed and the hoist was in service and working under different operating conditions. In the proposal stage, when the gear ratio is not yet determined, lengthening the acceleration beyond a normal value and gearing for higher rope speed to give the same time of trip, will invariably increase the root-mean-square.

Mr. Graham Bright: Increasing the accelerating rate will decrease the kilowatt-hours per trip but the root-mean-square does not follow the same law. There is a certain value of accelerating rate which if departed from in either direction will increase the root-mean-square.

Mr. F. W. C. Bailey:* Mr. Bright mentioned the impossible hoisting duties or cycles that are sometimes put up to him. I would like to inquire if that is not often due to the small capacities of mine cars, to hoist a given tonnage, giving an impossible number of trips.

Mr. Robert Linton: I might add a few figures on the North Butte hoist referred to a few minutes ago. This hoist was originally designed to handle 200 tons of rock per hour from a maximum depth of 4000 feet. We have operated it to a depth of 3600 feet, but it can be operated to 5000 feet when the workings are carried to that depth. The original cycle showed that driven

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direct from the motor there would be peaks of about 4500 horse-power; consequently, it was decided to install a motor-generator set with a fly-wheel weighing 100,000 pounds, driven by a 1400 horse-power, alternating-current motor. The direct-current motor on the hoist is 1850 horse-power. The hoist has operated satisfactorily, though it has not, of course, been operated as yet to the maximum depth or capacity for which it was designed. The skip holds seven tons of rock, and weighs about four tons. With the rope and cage, the total weight to be hoisted from 4000 feet would be about 42,000 pounds.

Referring to Dr. Unger's question, the deepest shafts in this country are at the mines of the Calumet & Hecla Mining Company, in Michigan. One of these is a vertical shaft over 5300 feet deep. The hoisting equipment consists of duplicate 6500-horse-power Nordberg steam hoists, with drums 24 feet in diameter in the center, tapering to 16 feet at the ends. The hoists operate in counterbalance and are designed to raise six tons of rock from a maximum depth of 6000 feet.

Mr. Graham Bright: What is the temperature at that depth?

Mr. Robert Linton: I do not know, but I do not think the rock temperature is very high in the Lake Superior mines.

Dr. John S. Unger: How rapid is the hoist—how many feet per second?

Mr. Robert Linton: Our normal speed at North Butte is 2700 feet per minute, with a maximum speed of 3000 feet per minute.

Mr. Graham Bright: That is a good point to bring out. We are frequently given a set of conditions where a certain output per day is desired, but the given conditions would throw us into an impossible cycle. That problem came up recently in connection with some mines in New Mexico. We proved that by putting in a proper size car the output could be secured without difficulty with a practicable rope speed. Another way is to adopt

the skip method of hoisting. If you reduce your rope speed it goes a long way toward cutting down the size of the equipment. If you can handle twice the load it means more than cutting the rope speed in two. We should get the output with as low rope speed as possible. For these high rope speeds a large portion of the capacity is determined by the accelerating and retarding periods. Anything you can do to reduce the rope speed, therefore, will cut down the capacity equipment, increase the efficiency, cut down the cost of installation, and make a safer and more practical operating condition.

MR. G. G. BELL:* The subject of Mr. Whiting's paper is very interesting, but it is one in which I have had a very limited experience, confined almost entirely to the apparatus for our Springdale mine. This apparatus is designed for a capacity of 500 tons an hour, the vein of coal being about 115 feet below the surface of the ground—about 190 feet lift for a cage, or 210 feet for a skip hoist.

The solid-end car appealed very strongly to us, on account of the lower car and track maintenance required. This practically necessitated the use of the skip hoist; although, since we started this work, we understand that one of the manufacturers has produced a cage with 135 degrees rotation for use with solid-end cars.

One of the principal advantages of the skip hoist is that as the hoist is made large enough to handle two cars of coal at a time, the speed of hoisting is very low, and therefore the power required for acceleration is a comparatively small factor. We are raising two cars of coal to the ground at each trip in two pockets mounted in tandem, one above the other, the gates on both pockets being controlled by one mechanism. This makes a large and heavy skip, the total pull on the rope being about 43,000 pounds. The acceleration factor is so small that the same frame motor can be used for a considerable variation in the speed of hoisting, permitting of reconnecting the motor at some later date for a considerably increased output. The effect of increasing the

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speed from 360 to 450 r.p.m. is to increase the power consumption per lift between four and five per cent. The drum is so shaped that the power required in starting plus acceleration is very little different from that required to maintain the load in motion at full speed. The cycle in this case is such that the demand at the beginning and end of the cycle is about the same—that is, about 550 horse-power and during the time that the load is being hoisted at uniform speed it is about 420 horse-power. This is, of course, a much more favorable cycle than could be obtained with a cage.

By installing a higher speed motor, we have obtained about fifty per cent. leeway over the average capacity which we expect to maintain. Such leeway would be extravagant to maintain with a cage hoist.

The adoption of the skip also resulted in being able to use a much smaller shaft than we could have with the cage. There was a special advantage in this, because between the surface of the river and the top of the rock, there were 60 feet of gravel, to penetrate with our shaft, and it was necessary to use the closed caisson method of sinking the shaft through the rock.

Mr. F. L. Stone:* The question that comes up most frequently in my experience in connection with modern hoisting is whether a geared induction-motor or a direct-current motor with generator field control, driven by a separate motor-generator set with or without fly-wheel is most applicable to the problem under consideration.

Many people have an idea that the line is drawn between the hoisting equipments with direct-current-generator field control, and the geared induction-motor on a basis of horse-power. Nothing could be further from the facts. From a financial standpoint the power contract is the only factor that enters into consideration. If the power contract contains any reference whatsoever to "instantaneous peaks", a competent engineer should carefully determine how the instantaneous peaks, caused by the geared induction-motor, will affect the monthly bill. This can be determined with a very fair degree of accuracy if the general conditions of operation about the mine are known.

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Even though instantaneous peaks are not penalized in any way whatsoever, cases frequently arise where it is still advisable to consider the installation of a direct-current equipment with generator field control. These cases are generally included under the general heading of very rapid hoisting of light loads from depths of 250 feet or more. In these cases the acceleration and retardation constitute such a large percentage of the duty cycle that the rheostatic losses with the induction-motor make its efficiency so low as to be prohibited. For example, a customer recently wanted to make four trips per minute from a depth of 250 feet, carrying only 3000 pounds of coal per trip. The geared induction-motor showed an overall efficiency of only 11.7 per cent. while a direct-current motor with motor-generator set, without fly-wheel, showed an overall efficiency of 36 per cent., saving 1.6 kilowatt-hours per trip. On the basis of a cent per kilowatt-hour, this would make a saving of approximately $8000 a year, if the hoist were operated in accordance with the duty cycle. By efficiency, I mean the foot-pounds energy of work expended in the shaft to lift the load, as compared with the energy taken from the line.

The control of the Ward-Leonard installation is considerably simpler than that of the induction-motor, for the reason that the motor speed follows the control lever almost instantaneously—either acceleration or retardation. During retardation, the motor becomes a generator and automatically pumps back into the line through the motor-generator set, thus forming the very best kind of a regenerative brake.

Mr. Bright has referred to the danger of "plugging" the induction-motor-driven hoist to bring it to rest. Should, for any reason, power fail during the plugging, if the hoist is running at any considerable speed it will overwind before the automatics can act.

Mr. W. B. Spellmire, *Chairman*:* Would you prefer to use brakes rather than plugging in an induction-motor?

Mr. F. L. Stone: No, brakes will not always do it as they are so uncertain as to their rate of applying braking effect. I do

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not believe brakes can be depended on to reduce retardation with any degree of accuracy at a higher rate than four feet per second, per second.

Mr. W. B. Spellmire, *Chairman*: What would be the control?

Mr. F. L. Stone: Ward-Leonard.

Mr. F. W. C. Bailey: How closely do the cage weights, as quoted, agree with the actual? You spoke about drum weights. Do they overrun to a large extent?

Mr. R. W. McNeill:* Mr. Whiting has covered pretty thoroughly the various points wherein the practical operating cycle of an alternating-current hoist motor may vary from the theoretical. I believe, however, that he has left the impression that the hoist operator, if very expert, can so skillfully regulate the point at which he cuts off power, as to make further applications of power at very low speeds unnecessary. In practice, however, we are frequently confronted with a condition where it is practically impossible for the most expert operator to achieve this result. This occurs in a great many fast hoisting cycles where what is known as the loose-rope system is used. In this system, the light cage reaches the bottom landing at about the same time that the loaded cage enters the dumping horns. This necessitates the loaded cage being hoisted unbalanced for several feet, requiring a high torque from the motor at a low speed. This means high input from the power line, high resistance losses, greatly increased heating of motor, and low efficiency. The most expert operator cannot avoid this condition where this system is used, as it is always necessary to slow down to land the light cage, and then make further application of power to dump the loaded cage. However, an unskilled operator can greatly aggravate this condition, not only in slowing down improperly as pointed out by Mr. Whiting, but also by coming into the dump improperly. Cases have come to my attention where the operator

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has entirely neglected to cut off power after coming to the dump; instead, he has applied his brakes, and left his motor soaking on the line.

While the advisability of using the loose-rope system at all may be regarded as questionable by some engineers, a great many operators consider it to be a better and safer way of increasing their output than by using higher rope speeds. Output is increased on account of the ability to load and dump at the same time, thus cutting down idle time.

As a general proposition, hoisting cycles which require such fast operation as to make the use of the loose-rope system necessary, are best met by using a motor-generator set with direct-current hoist motor and Ward-Leonard control, as by the use of this equipment, rheostatic losses are practically eliminated, accurate speed control is practicable, and high torques are available at low speeds—all with high efficiency. A great many people seem to think that a fly-wheel set is necessary in order to utilize the Ward-Leonard control system. This is not necessarily the case, as a synchronous motor-generator set can frequently be used to advantage where the power contract does not contain clauses penalizing momentary peaks. If, however, the power contract does contain such clauses, a careful analysis of the situation should be made before purchasing electrical hoisting equipment, as frequently the more expensive fly-wheel equipment will more than justify its increased cost by its lower operating cost.

Mr. H. B. Mann:* In calculating the duty cycle, in cases where self-dumping cages are used, is allowance made for the loss of balance, due to part of the cage resting on the horns at the start and end of the trip?

Mr. Graham Bright: Regarding the use of a hoist for water, instead of pumping: It is frequently necessary in the hard coal regions, to get rid of a large amount of water in a short time, where the water level changes very rapidly due to heavy rain fall. Pumps, in many cases, would be submerged before

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they could get ahead of the water. A hoist can be used, no matter what the water level may be, by simply changing the length of the rope as the water rises or falls. There is no delay in getting at the water, and the danger of flooding the pumps is avoided. Pumps are sometimes lost for days, and when recovered, the motor is out of commission and has to be taken out and overhauled.

Mr. W. B. Spellmire, *Chairman*: On the occasion of a visit some years ago to the Hampton mine of the Delaware, Lackawanna & Western Railroad, I was advised that the water hoist was a more efficient method of raising water than the centrifugal pumps in operation at the same mine, but that the initial cost of the water hoist was enormous as compared with the centrifugal pumps.

Mr. F. L. Stone: I do not remember the figures on this comparison but I believe the water hoist is held in reserve while the pumps are in regular service. I believe that the water hoist, however, is ready to start at any time in case of flood, or failure of pumps.

Mr. W. B. Spellmire: When I saw the hoist working, some years ago, it was operating at night, raising out of the mine water which had accumulated in a sump during the day. The water was discharged into a large pond and used by the power-house for condensing purposes during the daytime.

Mr. Graham Bright: I do not think any of our hoist cycles show an efficiency of over 60 per cent. Most of them run between 40 and 50 per cent. under the best operating conditions.

Mr. F. L. Stone: The best overall efficiency I have any knowledge of is 64 per cent.

Mr. Graham Bright: The pump will show better than 64 per cent.; in some cases it may be as high as 75 per cent.

MR. JOSEPH BRESLOVE:* At the mines of the Lehigh Coal & Navigation Company they have a lot of centrifugal pumps that run at an efficiency of 75 per cent. for the pump only. These are 10-stage, solid-bronze mine pumps.

MR. W. B. SPELLMIRE, *Chairman*: Mr. Mann, have you any idea of the approximate overall efficiency?

MR. H. B. MANN: I have never seen efficiencies quite so good for multi-stage pumps, although with large volumes of water the efficiency might approach 80 per cent. However, when the motor efficiency and friction losses are taken into account, it is questionable if the centrifugal unit will equal the 6½ per cent. efficiency stated for the water hoist. The cost of the water hoist and installation would have an important bearing upon the relative cost of pumpage.

MR. F. L. STONE: The efficiency of the hoist will stay constant while the pump is very liable to fall off in efficiency to quite an appreciable amount after running for a considerable time.

MR. W. B. SPELLMIRE, *Chairman*: An interesting point, somewhat aside from the issue, is that the water discharged by this hoist contained about 27 grains of free sulphuric acid per gallon, this acid condition causing considerable trouble with the centrifugal pumps. In using this water in the barometric condensers of the power-house it was found necessary to use lead-lined condensers to prevent the hot acid water from attacking the cast-iron of the condenser.

MR. M. A. WHITING: Dr. Unger's question as to the depth has been answered by Mr. Linton's reference to the Calumet & Hecla. For vertical or nearly vertical shafts I do not know of any greater length of trip. Two 5000-horse-power, direct-current equipments are now under construction for the Rand, South

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Africa, for a depth of 5000 feet vertically, to hoist 10,000 pounds of rock at 4000 feet per minute. Commonly, on account of the effect of a long rope in a vertical shaft, they consider that if they have to hoist much deeper than 5000 feet they will have to break up the hoisting into two stages.

In connection with Mr. Bright's discussion it occurs to me to emphasize the fact that when working up a mine-hoist cycle and considering what is a suitable time of retardation, we have to allow for what we may reasonably expect of the operator in judging the retardation. Where the rope speed does not need to be excessive it is unreasonable to assume a rate of retardation which means that the operator must be "on his toes" every second. But if it is a cycle which is difficult to meet—for example, three trips a minute—it is unreasonable to say that we must allow a long retardation. In the latter case, either it must be assumed that the operator is going to be a good man who will apply himself very carefully to learning his hoist, or the idea of an extremely fast performance must be abandoned.

Mr. Bright stated that in many cycles it is necessary to plug very much more heavily than shown in Fig. 4. It is one of the principal advantages of the cylindro-conical shape, which is a favorite shape for shallow induction-motor hoists, that it reduces the amount of plugging or braking necessary for even a very fast retardation. I have yet to find a cylindro-conical hoist for which the amount of plugging power required would be excessive, unless the time of retardation is assumed at two or three seconds, which is so short that it would not be practicable for the operator to judge his speed and stop on the marks.

When Mr. Bright explained that where severe plugging is required it is much better to use a direct-current drive with Ward-Leonard control, he then discussed the fly-wheel set. Many people do not have the distinction clearly in mind, but consider that a fly-wheel set is a necessary part of a direct-current mine hoist to obtain this perfect control of the hoist in retardation. Actually, the fly-wheel itself has nothing to do with the ease of control of the direct-current hoist. Ease of control is obtained because the system has a Ward-Leonard control. The fly-wheel is not selected for reasons of hoisting, but for reasons of power supply.

In connection with Mr. Stone's discussion of the cost of the fly-wheel set for equalization of the input, one thing should be pointed out for cycles in which the total cost, operation plus all investment charges, is slightly in favor of the direct-current system with Ward-Leonard control. For a mine in which, while producing, this comparison is only slightly in favor of the direct-current hoist we must consider the fact that while the mine is idle for long periods the direct-current equipment will have considerably greater fixed charges going on against it. Therefore, over a period of fat and lean years the total cost may be less for the alternating-current hoist. Whether to select direct-current or alternating-current equipment becomes, under this condition, a business problem rather than an engineering problem. Fortunately, in most cases there is a considerable difference in cost in favor of one system or the other, so that we can usually draw a definite conclusion for a given case.

As to Mr. Bailey's point regarding the cage weights being increased, they sometimes run as much as 20 to 30 per cent. more than given, and in a few cases slightly under. At Christopher they started in with an ordinary cage and later developed an automatic caging system. The cage was built so that, if the operator failed to bring the trip completely in, there was a bumper on the cage to stop the incoming loaded car. That and other features made a very massive cage and considerably increased the accelerating work.

Mr. Mann asked whether we figured the effect of the loss of balance on account of the cage at the top being in the horns. Ordinarily we do not take specific account of that because the effect is of so short duration and the energy involved so small that it is entirely within the limits of error of the entire calculation. In case the static load is high and the effort required for acceleration is low, we estimate this effect in order to see whether it appreciably robs the effort assigned for acceleration; if so, we assume a higher total torque during acceleration, to take care of this. Ordinarily, we do not show it in the duty cycle, because unessential details in the plotted cycle have a tendency to confuse.

I believe Mr. Bright's explanation of why the water hoists are used in some cases—that the water hoist will keep going in

case of a sudden rise which drowns out the pumps—while it may explain the installation of a water hoist, is a still better argument that a mine subject to water conditions of that character should have a pair of water buckets available for every hoist ordinarily engaged in production or tender work. I was on a large mining property on one occasion after two weeks of rain and found that in addition to two large water hoists they had every hoist in the place bailing water. After they had partly unwatered, some of the hoists went on production from upper levels by day, and bailing below these levels by night.

If from my oral presentation of the subject, the impression was obtained that a good operator can so judge the point of cut-off that further applications of power at low speeds are unnecessary, I am glad that Mr. McNeill cited conditions to the contrary. Whether this nicety of operation is possible depends on several conditions, principally the drum shape, rope speed, and ratio of weight of material to mass of moving system.

Where the design and operation of tipple and bottom do not require the cages to come in more slowly than the natural coasting rate, a cycle calculated for retardation by coasting can be closely approximated by the average performance. To meet this, the operator must endeavor not to cut off so early as usually to require an additional application of power, but should endeavor to come in, on the average, with a little speed to spare. Then additional power will be used at the end, to pull in some of the trips, and moderate plugging or braking will be used at the end, to stop other trips.

We must not overlook the fact that crawling in to the dump (except when operating with loose ropes) is wasteful of time to an extent that becomes serious when two or three trips a minute are required from depths of about 250 feet or more. In a busy induction-motor hoist, the failure to meet the intended cycle because of crawling in to the mark is much more serious on account of loss of tonnage than on account of increased energy required for hoisting.

POWER-PLANT INSTRUMENTS AND METERS

By E. G. Bailey*

Purpose of Instruments. Instruments and meters are used in the power-plant to visualize operating conditions for the purpose of obtaining better efficiency and capacity.

In the past the question of capacity has been emphasized more strongly than has efficiency and it is a matter of prime importance, for the man who maintains a high capacity with every piece of equipment in the power-plant is doing the work with a smaller investment and a smaller overhead charge than the man who is letting the boilers and generating equipment drift along at a lower rate and a poorer load-factor.

The question of efficiency is too often considered as applying to heat units only. While the cost of fuel is of prime importance, it is not the entire problem, for to-day we must consider labor, repairs and other items as well as fuel, and the man who is obtaining the best efficiency in terms of dollars is the one who is accomplishing the best all around results. It is well to bear in mind, when deciding between two methods of operation, that the one which gives a higher thermal efficiency, though at an equal or a slightly greater cost, should be given preference as a matter of conservation of our natural resources.

While instruments and meters have been used extensively in power-plants, they were largely confined to test work where they were in the hands of an experienced engineer who carefully calibrated and checked up all apparatus before and after the test. Such instruments were practically all indicating, and readings were taken at intervals of time throughout the test.

For a long time the operating engineer had nothing to visualize his operating conditions, except a pressure-gage, a water-glass, and the steam-engine indicator. Later, the ordinary thermometer came into general use, and a little later the recording pressure-

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gage and recording thermometer found their way into the power-plant and their use has been gradually extended until they are to-day very prominent as power-plant instruments and are serving a good purpose in a variety of uses.

Classification of Instruments. In comparatively recent years many additional instruments and meters have come into common use. These may be divided into three general classes.

1. Instruments to show condition (indicating and recording).
    a. Pressure
    b. Temperature
    c. Humidity
    d. Quantity
2. Meters to indicate or record rate.
    a. Steam flow
    b. Water flow
    c. Air flow
    d. Stoker speed
    e. Fuel supply
3. Meters to show relation.
    a. Steam flow, air flow, fuel supply
    b. Energy input, work output, turbines, pumps, etc.

The instruments of the first class apply particularly to fluids and material, showing the state or condition of these. Pressure and temperature are the most common factors. Temperature, for instance, is a measure of heat potential showing the state of molecular activity. Pressure is a state of molecular compression. Humidity is intended to be broad enough to cover the percentage of moisture and other factors of similar nature. Quantity is used in a varied sense; for instance, a level gage showing the amount of water in the boiler, the level of a liquid in a tank, or the amount of coal in a bunker. Integrating meters which show the total quantity up to a certain time also belong in this class.

Meters which indicate or record rate are extremely useful in the power-plant, as the entire operation is dependent upon the flow of fluids of various kinds and in various forms. We are all familiar with the rapid development that has been made since the venturi meter was first used as a means of measuring feed-water, after it had been previously developed in connection with water-works and other projects of the hydraulic engineer. Later forms of flow meters have been developed for measuring steam—both high pressure and exhaust—gases, oil, etc. Stoker speed and other similar factors are also classified as rate meters.

The third item, covering meters which show relation, is the most recent and most important development. The first two classes of instruments and meters give results that are, as a rule, of limited value until they are associated or compared with certain other results, and certain calculations or deductions made. In other words, the temperature of feed-water alone does not mean anything unless it is the temperature which applies to the average rate of flow. When the pump is running slowly, the temperature may be high, and *vice versa*. In like manner a boiler may be generating a great deal of steam but doing it very inefficiently with a very high flue-gas temperature, a large amount of unburned gas, and other prohibitive losses. It is, therefore, desirable to correlate certain factors which are properly associated, so that the operating engineer can see whether or not the best operating conditions are being maintained for both capacity and efficiency of each piece of apparatus in the plant.

Practically any one of the various types of instruments and meters mentioned in the three foregoing classes may be indicating, recording, or integrating, or any combination of the three types. For certain purposes, indicating instruments and meters are all that are necessary or desired. For other purposes, recording meters are of much greater value, and in measuring the flow of fluids it is desirable to have an integrated or totalized result in addition to the record. The total may be obtained from records by means of planimeters or radiimeters, but the total cannot be obtained from indicators unless they are read continually at frequent intervals.

Indicating vs. Recording Instruments. The question of installing indicating rather than recording instruments is one which most frequently comes up for decision. It has usually been considered that the recorder had its principal advantage in showing the chief engineer or the boss what was taking place throughout every hour of the day or night. This is a distinct advantage and is sufficient to decide the matter in most cases. There is also the further advantage that a great deal of valuable information can be obtained by comparing chart records from different types of meters, and working out therefrom important engineering data—showing the relation between temperature, rate of flow, efficiency, etc.—that cannot possibly be obtained by indicating instruments unless read continuously. The principal advantage of recording meters over those which indicate only, however, lies in the fact that the fireman or the operating man has the chart record before him at all times, enabling him to note whether or not he is maintaining uniform conditions, or whether he is accomplishing the desired results when he changes control, as in the case of the feed pump, stoker speed, draft, etc. For instance, if a fireman is looking after six boilers each of which is completely supplied with indicating instruments and he notices that one boiler is not operating satisfactorily, he may increase the stoker feed, and check the damper. He passes on to effect similar, or possibly reverse, adjustments in some of the other boilers and ten or fifteen minutes later, returning to the first one he changed, finds conditions that are still faulty. It requires an excellent memory for him to know whether the conditions have improved since his adjustment, or whether he overdid the matter and the error is now in the other direction. In other words, recording instruments show in what direction and at what rate conditions are changing and, for this reason alone, recording meters have a decided advantage over those which are indicating only.

A simple illustration is to consider a recording feed-water meter located in the chief engineer's office, giving the water tender nothing whatever to go by in regulating his pump or boiler feed, as compared with the recording meter located where he can have it under observation at all times. The water tender will do decidedly better work and accomplish much better results if he has

a recorder in view so that he can quickly make the adjustments necessary.

Accuracy. One of the first and most important points to be considered in connection with instruments and meters for power-plant operation is their initial accuracy and their reliability in maintaining this accuracy. Every instrument or meter that moves an indicating, recording, or integrating device requires some power to produce this motion. There is always some friction of the moving parts, or the surface tension or capillarity of liquids has to be overcome in producing this motion, and the accuracy of the indicated or recorded results depends upon the ratio of power to friction in the mechanism. Unless the readings are reasonably accurate, they are worthless. Any instrument or meter can give or indicate certain readings or figures, but it must be remembered that there is a vast difference between figures and results.

Care of Instruments. The use of instruments and meters has extended in power-plants somewhat faster than has been the development of the testing department, efficiency department, or results department to look after such work. Different plants apply a different term to this part of the organization. On the whole, I prefer the term "results department," because it concisely states exactly what is to be accomplished.

Many instruments and meters installed in power-plants have been of little or no real value, because the operating engineer failed to give them proper attention. The operating engineers who do not produce value from instruments and meters may be divided into three classes:

First, the man who is entirely unfamiliar with meters and instruments. His license examination requires little or no knowledge along this line, as it does with pumps, engines, and other equipment and he is afraid to touch the instrument, for fear he might do it damage.

Second, the one who fears nothing of this kind, and does not hesitate to take any instrument or apparatus entirely apart, without reading instructions—even to the extent of cutting the capillary connecting the bulb and recorder of a thermometer, and doing other similar foolish things—and then blames the meter for not working properly after it is reassembled.

Third, the one who is too busy to pay any attention to the instrument or meter. Oftentimes, in case of failure or inefficiency, a meter may be showing him exactly what is wrong with his plant, yet he is not well enough acquainted with its reading to interpret the results indicated, in solving his problems.

The real solution is to place the power-plant instruments and meters in the hands of someone who has thoroughly familiarized himself with them, both in detail and in the principle of operation, and who really knows power-plant engineering. The duties of such a man are threefold:

First, to make sure that instruments and meters are in proper adjustment and are giving results and not figures; also to select the proper instruments and so to locate them that the results are of prime importance in visualizing all operating conditions that are worth knowing.

Second, such a man—a results engineer, we will call him—should also know how to operate stokers, boilers, or other equipment in the plant so that he can fully explain to the fireman and operating engineer how to obtain the best results and how to interpret the readings of the instruments and meters to show whether or not these results are being obtained, and, if not, what should be done to accomplish them as quickly and efficiently as possible. In other words, the results engineer should interpret the results, in terms intelligible to the operating man and fireman.

The third function of the results engineer is to calculate, plot, and tabulate the results in such form that he can keep an accurate and reliable check on all equipment and apparatus and bring to the attention of his superior—who may be the chief engineer, superintendent, or manager—any improvement in the method of operation or the installation of new equipment, in order to obtain better results; and to be able to back up his recommendation with results that can be substantiated.

There is a real field in the power-plant for such men. This has already been appreciated and many concerns are carrying this out exactly as outlined. They are not always young men, for men of ripe experience are taking up this work. With the present soaring price of coal, labor and material, this work is going to be extended into a larger number of plants, including many of even

smaller capacity, and the efforts of such men are going to be appreciated by those who are controlling the financing of power-plants and industry.

To return again to the three different classes of instruments and meters, I believe the first, covering those which show conditions, is so well known to everyone that these instruments need not be discussed further.

Flow Meters. Of the second class there is also a very general knowledge to-day, but in regard to the orifice type of flow meters there are a few points that are not fully understood by all power-plant men. These it might be well to explain briefly.

The sharp-edged orifice has been calibrated and used a great deal for measuring water and air flowing from tanks and reservoirs, usually designed for a considerable pressure differential, oftentimes amounting to several pounds. From time to time it has been tried in pipe-lines, instead of pitot tubes and venturi tubes, for the purpose of measuring the flow of fluids. Its successful use was limited, however, to very low capacities, or, in other words, to cases where the ratio of orifice diameter was small. It has since been learned that under these conditions pressure connections could be made at almost any point, and the same coefficient obtained which had been determined in connection with the discharge from tanks and other large vessels where the velocity of approach was very small.

Those who first used the thin-plate orifice between a pair of pipe flanges for measuring the flow of fluids at a high velocity with a small differential, requiring a relatively large opening in the plate as compared with the pipe, found very discordant and apparently unreliable results. Subsequent experiments have shown that this was due to the fact that the early users of the orifice failed to realize that in principle it was identical with the venturi tube and a great deal depended upon where the pressure connections were made, especially on the outlet side. Some details of the orifice characteristics have been fully covered in other papers,*† so I will mention here only the final development and its practical application.

*Horace Judd, Experiments on Water Flow Through Pipe Orifices, Trans. A. S. M. E. 1916, v. 38, p. 331.

†E. G. Bailey, Steam Flow Measurement, Journal A. S. M. E. 1916, v. 38, p. 776.

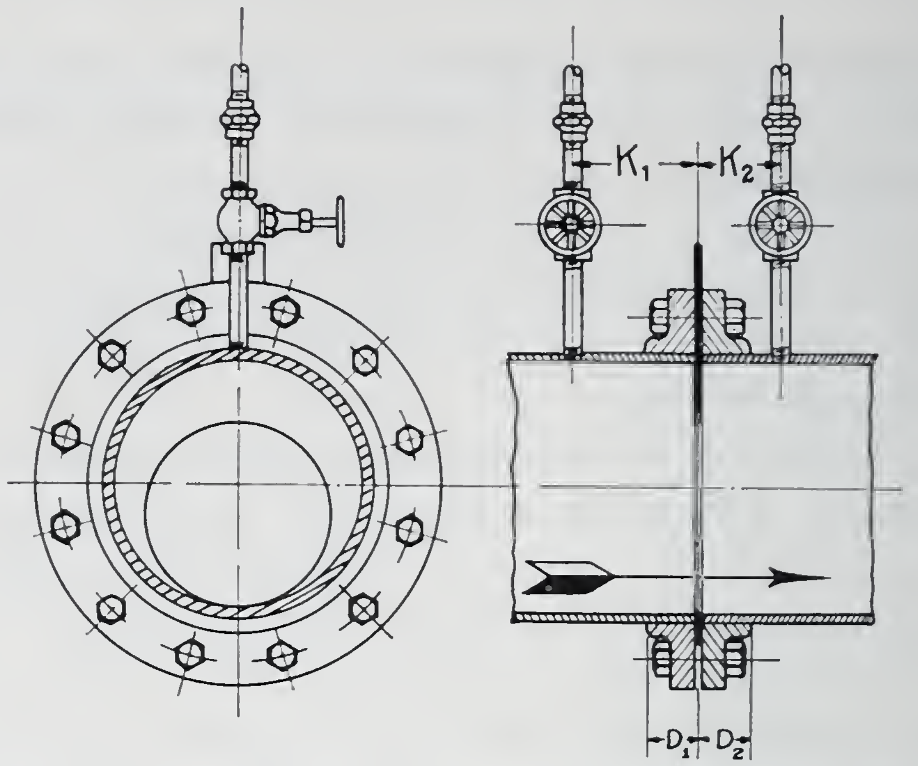

Fig. 1. Thin-Plate Orifice for Gas Measurement.

Fig. 1 shows an orifice located in a horizontal gas line. The opening is circular, but eccentric with regard to the pipe, so that the hole is flush with the bottom of the pipe with no chance for condensation or other substance to accumulate. The pressure connections are taken out from the top of the pipe, and may be connected to any form of indicating or recording meter.

A similar type of orifice is used for measuring dirty water, the connections being made from the side of the pipe instead of the top, in order to prevent the accumulation of air pockets which would otherwise destroy the true transmission of the pressure differential.

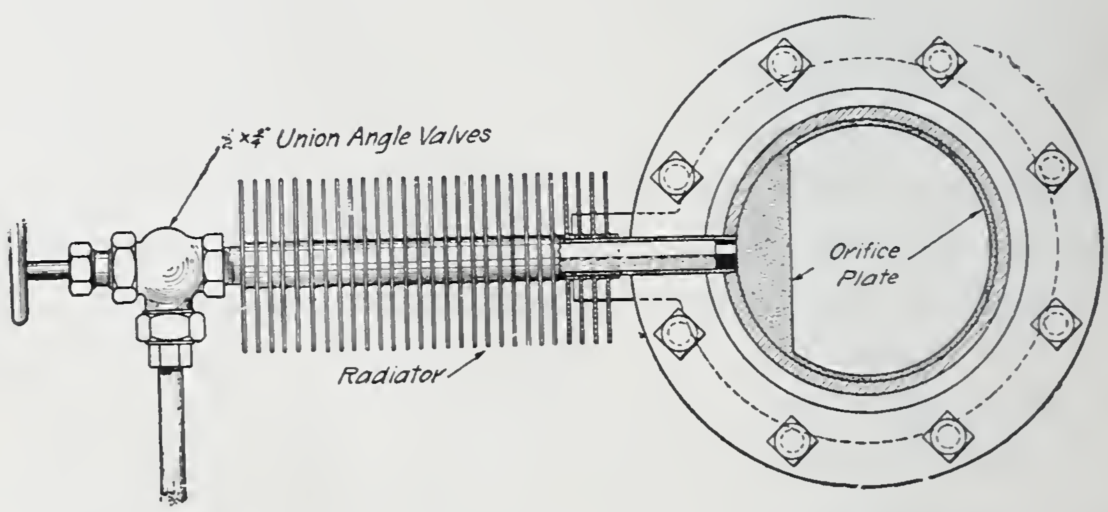

Fig. 2. Thin-Plate Orifice for Steam Measurement.

The orifice shown in Fig. 2 is segmental, having a narrow angular ring around the edge of the pipe, the dam or restricting

portion being a segment immediately in front of the pressure connection. The principal purpose of this is to cause a dependable *vena contracta* to be formed at a desirable distance from the orifice plate, so that the connection can be made without interference with the flange, which may already be installed in the pipe-line.

In the case of measuring steam, the pressure connection pipes are usually at the side so as to be free from accumulated air and also to form a reservoir for maintaining equal water level in the two connecting pipes. Fig. 2 shows such an installation, the radiator being supplied with fins so that as soon as there is a displacement of water caused by the motion of the meter, steam is condensed to take its place and maintain equal water level in both connecting pipes. The connecting pipes to the meter are shown in Fig. 3.

Fig. 3. Pipe Connections for Meter Shown in Fig. 2.

Fig. 4 illustrates three different types of orifices each having the same capacity, but of different designs, to suit the flange dimensions and the opportunity for tapping the pipe. In the upper view a circular, concentric orifice is used and the down-stream connection, at a distance of K_2 from the orifice plate, must be

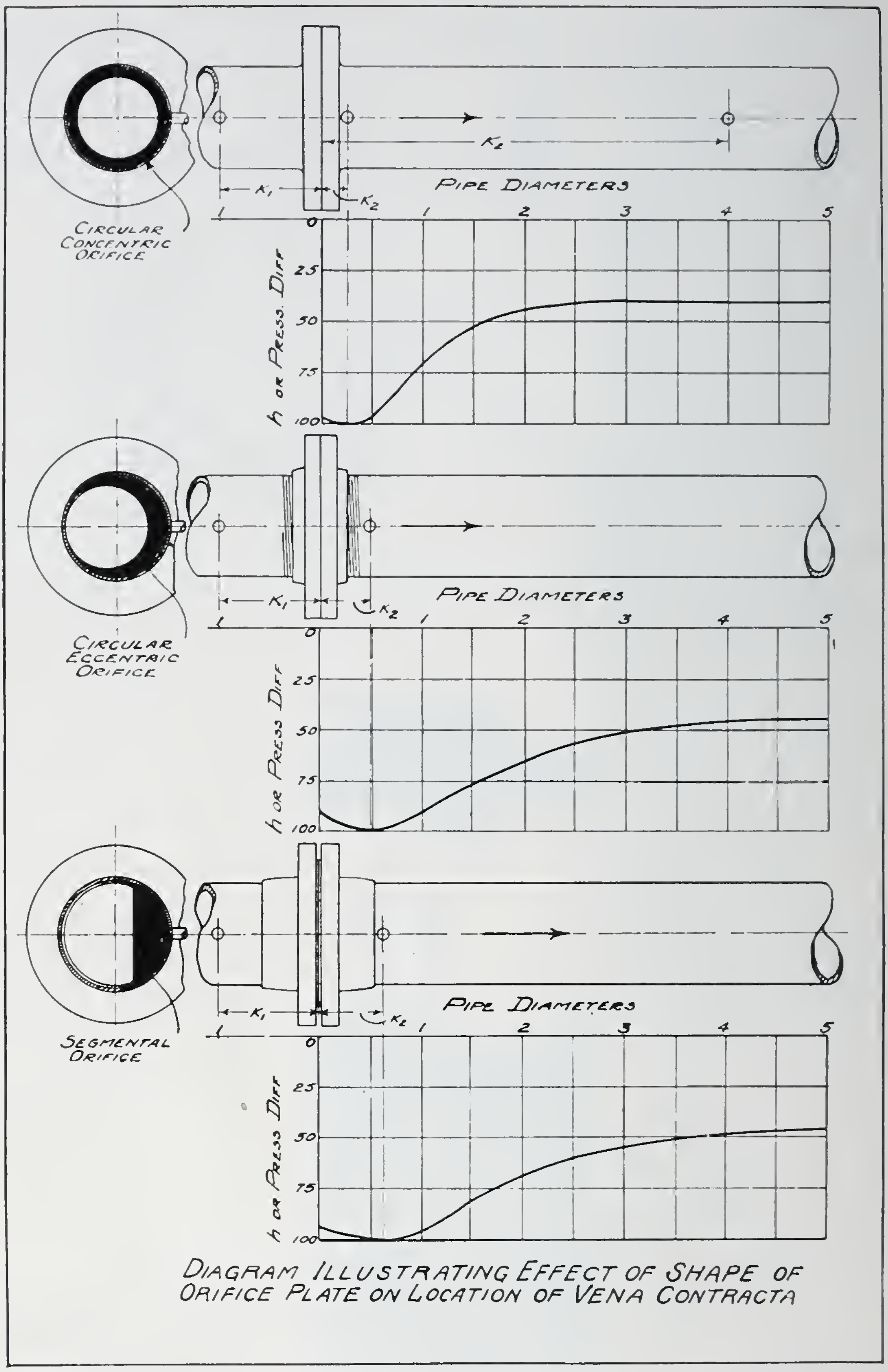

Fig. 4. Effect of Shape of Orifice Plate on Location of *Vena Contracta.*

very short in order to be opposite the *vena contracta,* or the point of maximum differential, which is shown here as about one-fourth the pipe diameter. With a thin flange, as shown, this can be accomplished and an orifice of this style is suitable. However, if the flange were thicker and the threads had to be cleared, as in

the second figure, it would be necessary to use an eccentric orifice, having the larger projection on one side next to the connection, so as to throw the *vena contracta* about one-half the pipe diameter away, and it is also noted that the pressure differential curve is somewhat flatter, so that a little more leeway may be allowed in locating the connection.

In case a vanstone flange be encountered, it will be necessary to use the segmental type of orifice as shown in the lower drawing. This, it is noted, throws the *vena contracta* about 60 per cent. of the pipe diameter away.

In the upper diagram, two pressure connections are shown on the down-stream side at distances of K_2 from the orifice plate, the longer one at four pipe diameters. This is sometimes used for a still higher velocity than can be obtained when using the eccentric or segmental orifices. It will be noted that, due to the restoration of the differential pressure, the net pressure loss is only 40 per cent. of the maximum and, if the differential pressure across these two connections were applied to the same indicating or recording meter, it would have about 60 per cent. more capacity than the meter connection at the short K_2 distance. In this case, the differential applied to the meter would be all lost in friction while, in the cases with the connection made at the *vena contracta,* the actual loss in pressure is only about 40 to 45 per cent. of the differential applied to the recorder, due the restoration on the venturi principle.

The orifice, as well as the pitot and venturi tube, produces a differential pressure proportional to the square of the velocity or rate of flow of flowing fluids. The extremely small differential at the lower rates of flow, makes it difficult to secure the desired accuracy over the lower ranges. For instance, the differential pressure is only one per cent. of the maximum when the rate of flow is 10 per cent. of the capacity of the meter.

Fig. 5 shows a specially shaped bell which is sealed in mercury, and weighted on the outside of the mercury reservoir so as to be submerged to the point of greatest diameter in the position of zero flow. The higher pressure from the inlet side of the orifice is connected through the center pipe to the interior of the bell, while the lower pressure comes into the meter casing.

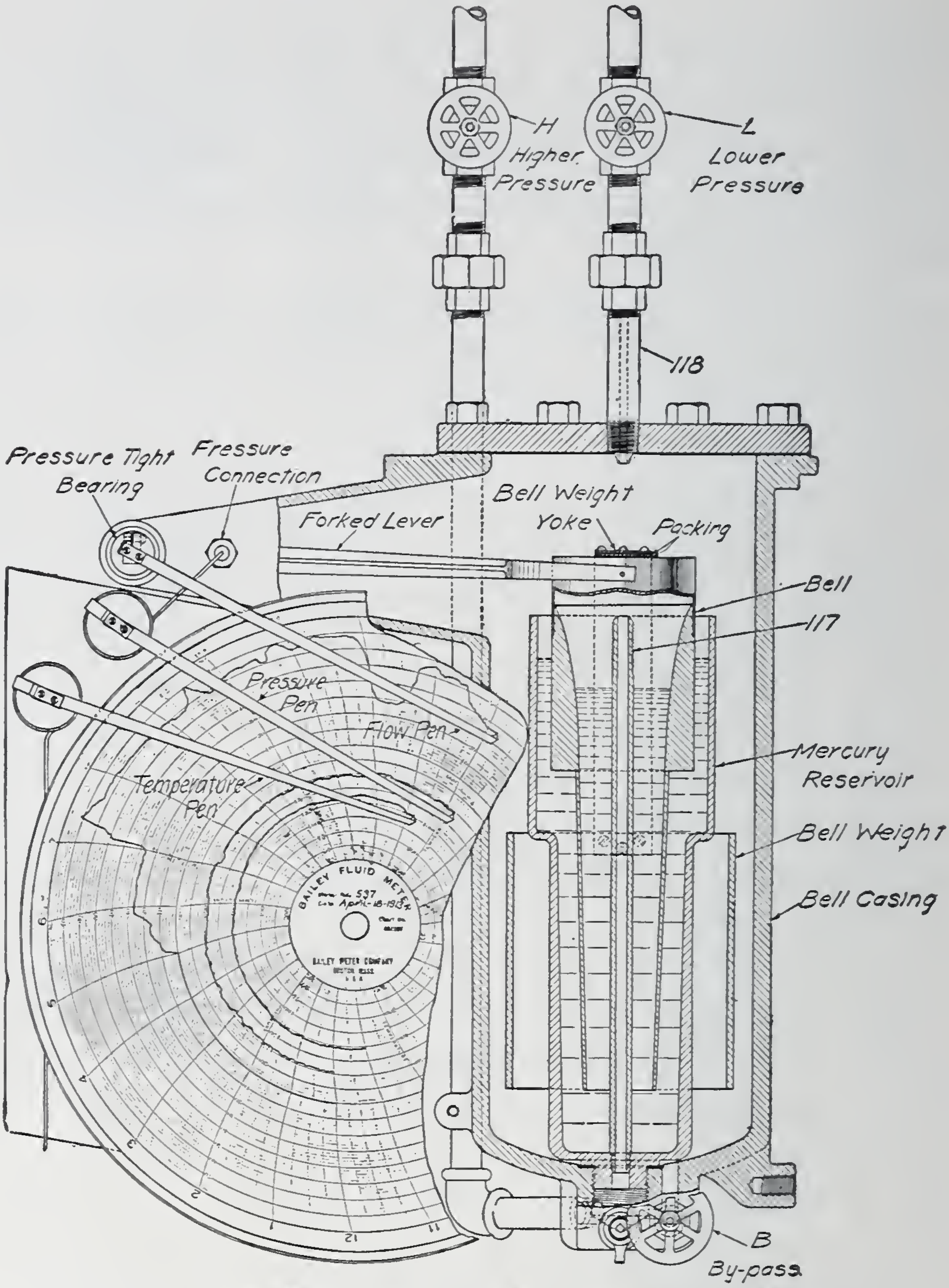

Fig. 5. Flow Meter with Bell Submerged in Mercury.

When metering steam or water, the entire casing and connecting pipes are filled with water or condensed steam.

A very slight differential pressure produced by the lower rates of flow introduces a force over the entire area of the bell, pushing it upward. As the bell rises to the position shown in the diagram, the differential pressure corresponding to the change in mercury level, within and without the bell, pushes the bell upward until the emerged volume of the walls of the bell equals the volume of mercury displaced in the interior. The shape of

the bell is so designed that the motion is directly proportional to the rate of flow. This not only gives a uniformly graduated chart, but it is also very effective in increasing the accuracy of the lower rates of flow, due to the relatively large ratio of power to friction, as compared with a meter that has a force directly proportional to the differential.

It is noted in Fig. 5 that pressure and temperature are also recorded on the same chart with the rate of flow.

Fig. 6. Exterior View of Meter Shown in Fig. 5.

Fig. 6 shows the outward appearance of such a meter, which has an integrator operating directly from the bell mechanism.

Meters To Show Relation. Very few of the individual readings or results from instruments or meters are of great value in themselves. It is only when they are used in calculating certain results or used for comparison with certain other quantities or results that they indicate whether the operating conditions are good or bad.

For instance, steam flow alone is of little use unless we know how many kilowatts are being generated from the use of this steam. To know merely the steam output from a boiler is only half of the story. It may show whether or not the boiler is developing its desired capacity, but it gives no indication whatever as to whether or not this is being done efficiently, until it is compared with other factors such as weight of coal, quality of coal, amount of air used for combustion, flue-gas temperature, etc.

The third class of meters showing the relation between different factors has been developed for the purpose of giving the fireman and power-plant operator the maximum amount of condensed net results instantly so that he can control his operation immediately and thereby take the necessary steps to secure the desired capacity and efficiency on each unit at all times.

In the case of combustion, to know merely the steam flow and the percentage of CO_2 is not sufficient because it is very seldom that the highest percentage of CO_2 which can be obtained is that which should be striven for. Depending upon the size of the combustion space CO and unburned gases will be formed with varying percentages of excess air. With the latest and most approved boiler settings having large combustion space it is possible to go as high as 16 per cent. or more of CO_2 with about 20 per cent. excess air before any appreciable amount of unburned gas is produced. This point, however, is so close to the theoretical air supply that if the fuel bed be increased very much beyond this point unburned gas will be produced very rapidly and very great losses will result therefrom.

Fig. 7 shows a diagram of gas analysis running from about 180 per cent. excess air down to a deficiency of some 25 per cent. which represents producer gas conditions. It will be noted that the percentage of CO_2 falls off rapidly after the point of theoretical air supply is passed. In the case of furnaces having very

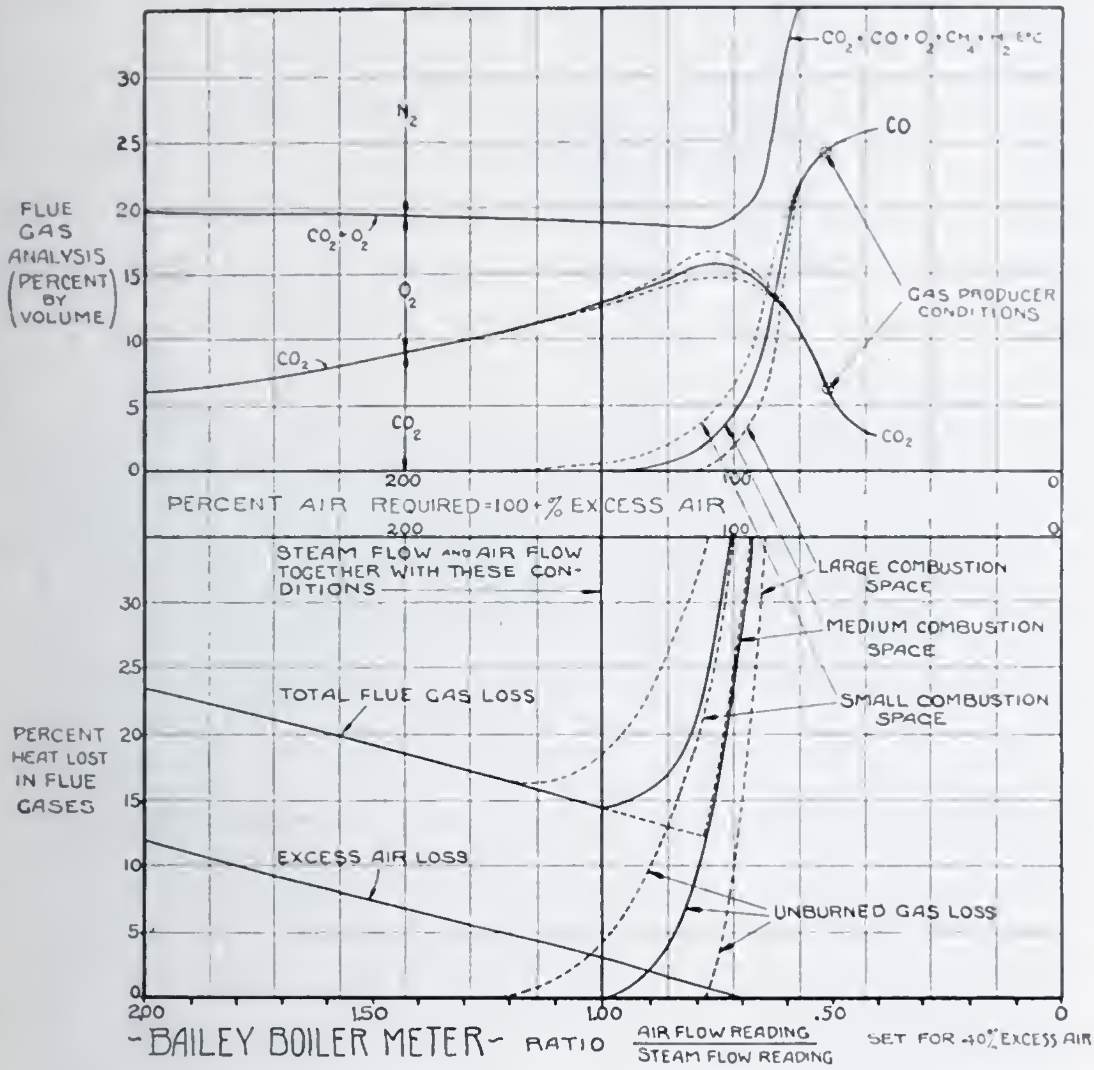

Fig. 7. Diagram Illustrating Flue-Gas Analysis, and Heat Lost in Flue-Gas.

limited combustion space, CO and unburned gases may start to form with an air excess of 60 per cent. and a CO_2 content of 11 or 12 per cent. In this case the most economical condition of fuel bed would be one which would produce these results while giving neither more excess air nor any appreciable amount of unburned gas. The average of the better modern practice is shown in this diagram as the one corresponding to medium combustion space where the excess air can be reduced to 40 per cent. above the theoretical before unburned gas is formed to any appreciable extent. This corresponds to about 13 per cent. of CO_2. It is obvious from this diagram that the combustion should be maintained at this point. A thinner fire will produce lower CO_2 and higher loss due to excess air while a thicker fire will produce an increased loss due to unburned gases.

Under these ideal operating conditions a definite amount of air is required to consume the available hydrogen and carbon in the fuel. When this amount of air combines with these elements it produces a certain amount of heat which is just as definite in proportion to the amount of air as it is to the amount of carbon and hydrogen. We may therefore, speak of the heat produced per pound of air. When such heat is produced and properly absorbed by an efficient boiler a certain amount of steam will be generated. We may, therefore, compare the amount of steam produced with the amount of air used for combustion and obtain a very reliable indication of the efficiency of the combustion taking place in the furnace.

This has been accomplished by such a meter as shown in Fig. 8, which records the steam output from the boiler reading directly in per cent. rating and also records the rate of air flow through the boiler passes. The latter is operated by the differential pressure across the boiler, the boiler passes acting the same as an orifice and the rate of flow producing an increased reading. This part of the mechanism is adjustable so that, regardless of what the resistance of the boiler passes may be or what percentage of excess air is desired to obtain the best combustion efficiency, it can be made to synchronize the air flow reading with the steam flow so long as the desired relation is maintained between air used for combustion and steam produced therefrom.

As shown by the scale at the bottom of Fig. 7, the ratio of the air flow reading would be 1.00 when this condition exists. Whenever the air flow reading is greater than the steam flow reading, producing a ratio greater than one, it indicates an excess of air and a condition which should be remedied by eliminating the holes in the fuel bed or increasing the thickness of the fire so that the air will come in proper contact with the fuel and produce its full quota of heat. On the other hand, if the fuel bed be too thick and a less amount of air than that desired be passing through the boiler, the reading for the air flow will be less than that of the steam flow so that the ratio of the two readings will be less than one, say 0.90, which would indicate a loss due to unburned gases caused by the fuel bed being too thick and approaching the producer condition. It is, therefore, the duty of a fireman to see that

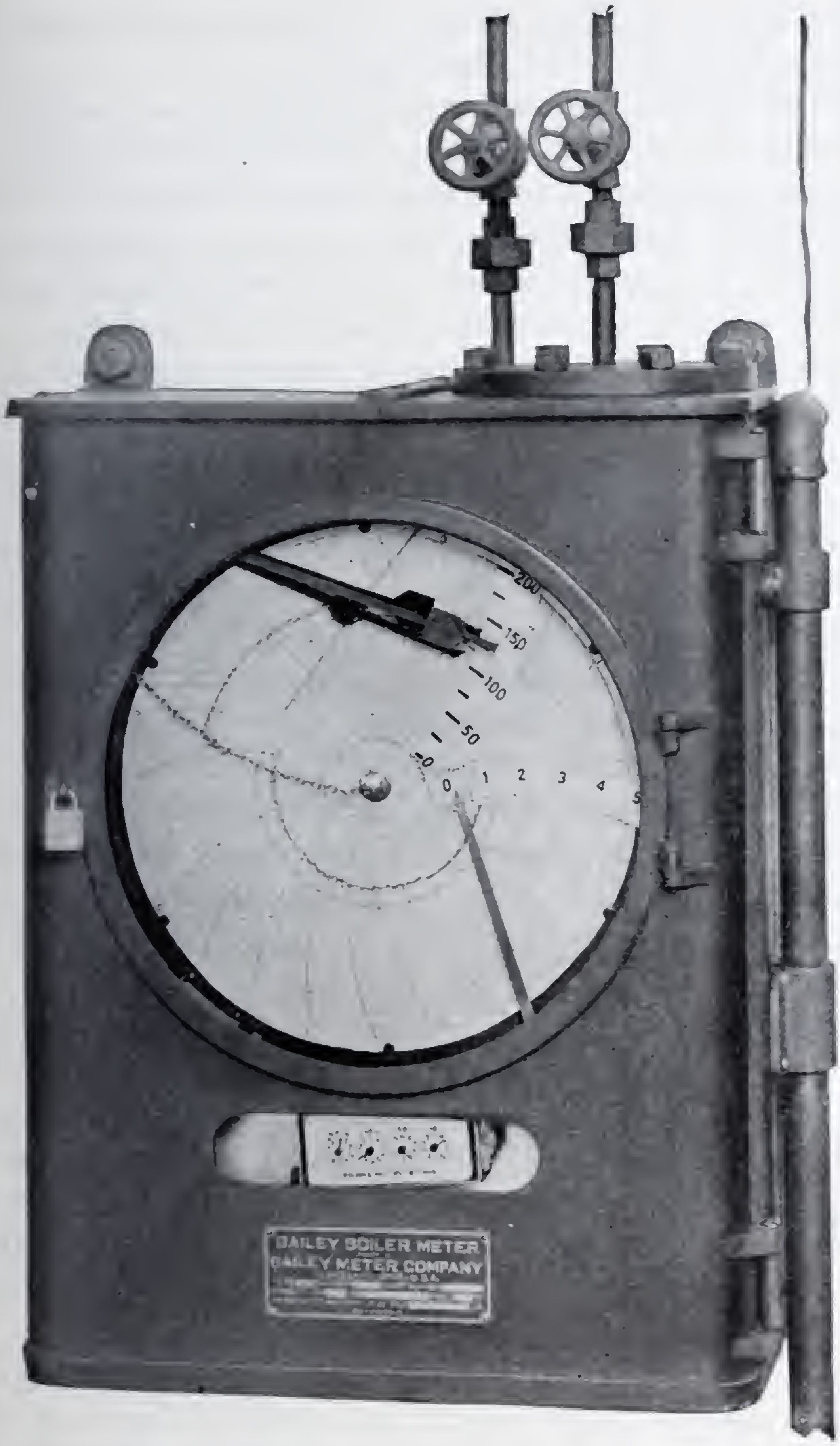

Fig. 8. Recording Meter for Steam Output, and for Rate of Air Flow.

the fuel bed is maintained in such a condition that the steam flow reading is always the same as the air flow. He can then increase or decrease the supply of air by changing his damper or wind-box

gate and damper until the air flow recorder indicates the per cent. of boiler rating which he wishes to carry.

We know that the amount of air required per pound of carbon and per pound of hydrogen, is a perfectly definite amount, and the B.t.u. production is also very definite; therefore, if desired efficiency is being obtained, the relation between the steam output and the air input to a furnace is a perfectly reliable guide for operation, with respect to both capacity and efficiency.

The problem has been to meter the air accurately, so that this comparison could be made with assurance. This has been accomplished, and the results are very dependable as long as the boiler resistance remains at all uniform. The two factors which are most likely to cause this to change are accumulation of ash and soot on the tubes, and the deterioration of baffles. Neither of these causes will produce an increase in flue-gas temperature. This temperature reading alone is well worth knowing, so it is also incorporated on the same chart with the air flow and steam flow, thus permitting the operating engineer to observe, at any time, whether or not he is getting the full absorption of heat from the combustion of fuel. This readily detects any leaking baffle or dirty tubes, and in fact nearly every installation shows a drop in temperature of 30 to 70 degrees at the time tubes are blown, for intervals of 12 to 24 hours.

Other types of meters belonging to this class include the rate of stoker speed, as well as the steam flow and air flow, the latter being adjustable according to the evaporation per pound of coal, so that stoker speed readings should be synchronous with the steam flow and air flow, as long as the coal is being burned at the proper rate to carry the load. This is naturally limited to certain types of stokers, where the amount of coal fed is closely proportional to the rate of a driving shaft.

There are several other factors of interest in the operation of boilers, such as the fire-box draft, wind-box draft, and superheat temperature, which may also be indicated or recorded on the same meter with the other factors, thereby giving a complete log of all operating conditions. Thus at whatever rate he is called upon to operate the boiler, the fireman or operator can control his capacity more intelligently and be assured of better efficiency,

than if he had the same information given at various sources which would require the calculation or correlation of one to the other before he could definitely determine what should be done to produce the desired results.

The best method of understanding the application and use of such instruments is to show the proof thereof. This is established by the chart records from the various types of meters and instruments described herewith.

Several chart records, having as many as three and four records with different colored ink on each, were shown by means of a special balopticon; but, unfortunately, due to the inability to reproduce these properly in colors, they must be omitted from the printed paper. However, certain of these chart records are reproduced in reduced scale in certain bulletins published by the author's company. These will be mailed on application, and from time to time additional chart records of interest will be reproduced in full size, in original colors, showing very interesting operating conditions from various types of boilers, stokers, turbines, and other equipment. These will be gladly furnished to any engineer requesting copies.

DISCUSSION

Mr. A. Marsh: You spoke of having what you might call an expert to look after the meters of the various plants. Can you give us any idea of the frequency of desirable calibration and the rate of change of the accuracy of the instruments in use? In your measuring of the volume of air it would seem to me, not knowing anything about it, that it would be quite a job to calibrate the instruments. How is that done and how frequently is it necessary?

Mr. E. G. Bailey: The frequency of calibration of instruments in general, and the rate of change in accuracy depend a great deal upon the instruments and the conditions under which they operate. Some types of pressure and temperature recorders should be checked every few weeks and the necessary adjustments made, while some temperature and pressure recorders in operation to-day have been in continuous use for 15 or 20 years.

The more complicated a meter the more attention it needs to make sure that it is in proper operating condition but that does not necessarily mean that it must have frequent calibration. Meters in power-plants should be inspected frequently to make sure that everything is all right—the same as is done with pumps, turbines and other equipment, on the basis that "a stitch in time saves nine."

In regard to air flow on the boiler meter, this mechanism does not need any closer attention than anything else and experience has shown that it does not need frequent re-calibration due to changes in its mechanism or the resistance of the boiler upon which it depends for its reading.

There are two factors which may affect the air flow reading so far as changes in the boiler are concerned. First, the accumulation of ash and soot on the tubes. Second, defective baffling—one tending to increase the air flow reading and the other tending

to decrease it. Both, however, have a marked effect in increasing the flue-gas temperature, and with this recorded on the same chart with steam flow and air flow it gives an excellent check on these conditions which could be maintained at normal. It has been found that any change which will affect the air flow reading by as much as three per cent. will cause an increase in flue-gas temperature of 100 degrees or so. It is, therefore, obvious that neither of these factors should interfere with the accuracy of the air flow reading at any time.

Should both of these conditions change they tend to neutralize each other, and experience has shown that when the tubes get dirty the baffles are very likely to get in poor condition because they are both a result of neglect.

It is well for the results engineer to keep in close touch with the actual conditions with respect to combustion and make sure that the air flow reading is correct. In this connection it is well to state that flue-gas analysis, alone, should not be depended upon, for the power-plant should take a lesson from the metallurgical furnace man's experience and judge the efficiency of combustion largely by the appearance of the flame and the fuel bed.

Mr. C. F. Cone:* I enjoyed Mr. Bailey's paper very much. A few questions come up, however. In his orifice he shows a particular place where he must make the down-stream tap. How much may that be off before it affects the accuracy of the meter? You tell the pipe fitter to make that tap two inches and he may make it 1¾ or 2½ inches. Will that affect the accuracy? In regard to flow meters in boilers it was stated that the real value comes from the operating man. If that is the case, why isn't the indicating feature the most important? A chart does not mean very much to a fireman or boiler-room foreman because a small variation on the chart means a large variation in the horse-power; whereas, if he has a large indicating needle, it is magnified and he can see without walking up to the instrument just what his condition is. Regarding the air flow and steam flow line, does he actually set that air flow line for his steam line at full rating, or does he get that reading from the condition of the boiler fire?

*Salesman, General Electric Co., Pittsburgh.

MR. E. G. BAILEY: The allowance permissible in making the down-stream connection depends altogether on the rates of the orifice diameter to the pipe diameter. With small orifices and low velocity a variation of an inch does not make any appreciable difference in accuracy. On the inlet side anything under ¼ of the pipe diameter is not of any appreciable effect. In very high velocities the *vena contracta* comes in closer and there is a sharp change. The limit there of ¼ inch in very few cases amounts to as much as one per cent. The difficulty of making a connection within that ¼ inch is not prohibitive. A pipe fitter who will miss it ¼ inch is just as likely to miss it by three or four inches due to his ignoring instructions.

Regarding the question of a fireman finding an indicator as valuable as or more valuable than a recorder, I stated in the early part of my talk that the principal value of a recording meter is for the operator to see whether he is coming or going. Some of those records are just like the outline of a sun flower. No fireman can be proud of a record like that if it is within his control to rectify it, and in most cases it is. That is a case where an indicator never tells any tales either to a fireman, or boss, or any one else. The real result in efficiency and capacity must be obtained by the operator at the time, except in matters of design, and that is an engineering question both in construction and alterations. The real boiler-house capacity and efficiency problem comes right down to the man. He has so many boilers to operate to carry a certain load and is given an unlimited value in fuel to do it with. The question is to get it with as small a number of boilers as possible and at minimum cost. He finds his conditions wrong, for instance, and changes his stoker speed. The change will not be shown instantly. With the indicator, he must remember from the time he changes the speed until he looks at it again to compare it, and he will never remember it if he has very many boilers to look after. With the record it is all before him and he can tell instantly whether he is coming or going; he can see whether the change he previously made was in the right direction and of the right amount. A record of any kind will give a lot more uniform steam chart than an indicator gage.

On the question of air flow being adjusted to the steam flow, that is a matter of boiler resistance. Some boilers have a great deal more resistance than others. The Bigelow-Hornsby, for instance, has about the minimum of draft differential across the boiler, while a four-pass Babcock & Wilcox has the maximum differential. If you want to operate each one of those at 200 per cent. rating you have got to supply the same amount of air. The differential reading on the air flow set will be a lot higher on the four-pass Babcock & Wilcox than on the Bigelow-Hornsby. The adjustment of the air flow meter is simply a magnifying of the mechanism of the air flow so that, regardless of the differential you get your 200 per cent. air flow reading for 200 per cent. steam output.

MR. W. B. SPELLMIRE:* In the operation of an electrical power-plant, it has been found desirable to use both curve-drawing and indicating instruments to observe the performance of the output of the turbines in the power-house; thus, indicating wattmeters on each generator panel of the switchboard will show at a glance the distribution of load between the various units. A curve-drawing instrument may make a continuous record of the total load or, if so connected, can make a permanent record of each individual unit, but the station operator looks to the indicating wattmeter to divide the load properly. Similarly, in a boiler plant, an indicating flow meter on each boiler will show the fireman, at a glance, the relative load on each boiler. A curve-drawing instrument, either on the total load or on each boiler or group of boilers, will make a permanent record of the boiler performance. Neither of the two types of instruments will satisfactorily fill the purpose of the other. There is no competition between indicating and curve-drawing electrical instruments, as they serve different functions. Similarly, there is no occasion for competition between indicating and curve-drawing flow meters, as each serves its own purpose.

MR. J. F. TUTEIN:† I would like to ask the gentleman who just spoke what he would do in a plant of a hundred boilers, if

*Manager, General Electric Co., Pittsburgh.

†Steam Engineer, South Side Works, Jones & Laughlin Steel Co., Pittsburgh.

the steam was down and he wished to know which boilers were falling down; bearing in mind that it would take at least half an hour to make a survey of all the indicating meters in the plant.

Mr. W. B. Spellmire: In this discussion, I had in mind a modern power-plant with a relatively small number of boilers, of proportionate size. If a hundred or more boilers are feeding into the same system, the problem is the same as if one hundred or more turbo-generators were feeding into a common bus system, and indicating and curve-drawing meters would be used accordingly.

Mr. C. J. Fechheimer:* I would like to ask whether the flow meter can in any way take care of the quality of the steam; that is, if steam is wet or superheated, how can allowances be made for those two factors? I would also like to inquire whether, in measuring differential pressure, there is difficulty in eliminating the influence of the velocity head. The principle of the meter Mr. Bailey shows is based on the use of an orifice instead of a venturi. Could Mr. Bailey tell us the advantages of the orifice over the venturi principle.

Mr. E. G. Bailey: The question of moisture or superheat is one that affects all flow meters the same as the density of the flow fluid comes into the flow formula. I do not know of any meter that will automatically correct for changes in superheat or changes in moisture. There may be changes in adjustment that you can make as the superheat varies, but, in gas, this question also brings in the question of temperature and specific gravity of the gas. That is a point that is still open for all comers to design an appliance to go with the meter, that will automatically correct for any changes in density. Superheated steam practically takes care of itself. If you have a meter designed for 100 degrees superheat, and you operate 150 degrees superheat, your steam is less dense. Your meter reads higher than on a 100-degree basis. it also has a higher B.t.u., and the additional B.t.u. is almost

*Research Engineer, Power Engineering Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

directly proportional to the higher reading so that it automatically takes care of itself within a fraction of one per cent. Moisture is not taken care of by any meter on the market.

As to the velocity head; on the inlet side the velocity head is on a par with the measuring inlet pressure of the venturi tube. I take that what you mean is, can the true static pressure be measured independently of the velocity head? If the connection does not protrude into the pipe and give you a suction effect, and there is roughness there, you can get the true pressure. The higher the velocity the more caution you use in making the connection, in any pressure that is supposed to represent the static pressure only. At the throat of the *vena contracta* is where you have the highest velocity; but the pressure connection is removed quite a distance from it with nothing but a fluid medium transmitting the pressure, while in a venturi tube you have your connection right at the *vena contracta* with the very highest velocity going right by the edge of the hole. At that point, the venturi is much more hazardous in getting the true static pressure than is the orifice. The fact that it is difficult to obtain the true pressure is borne out by the fact that the venturi has several holes to average that pressure. Now, when you stop to think of averaging pressure, you can't do it. You have a flow in through one connection and out through another. What you have left, all depends on the size and location of those holes, the resistance in the connecting passage, and where the averaging connection is made.

Mr. C. J. Fechheimer: About how many inches of water do you measure for normal flow?

Mr. E. G. Bailey: A maximum capacity of 53 inches of water head—about two pounds.

Mr. C. J. Fechheimer: Your error would be comparatively small.

Mr. J. R. Buchanan:* Mr. Bailey says the air flow for 200 per cent. boiler rating might be different with different boilers.

*Local Engineer, General Electric Co., Pittsburgh.

How is that determined as to the proper flow necessary to produce the 200 per cent. steam flow?

Mr. E. G. Bailey: That is all a matter for the results engineer, or the man who is in charge of the plant. If you can go down to 20 per cent. excess air without CO, there is where you will set it. If you have a very restricted combustion chamber and can not operate less than 70 per cent. excess air without getting CO you would set it at that point. That is entirely in the hands of the man in charge of the plant.

Mr. J. R. Buchanan: Is that subject to change from time to time?

Mr. E. G. Bailey: Not very much. The question of the character of the fuel does not change the most efficient point. It may change the labor required by the fireman to maintain that most efficient point. If you get a high-ash, clinkering coal, the result shown by any meter is lowered capacity and higher excess of air, because the fireman has a great deal more work to do. His work is not in proportion to the steam he is putting out nor in proportion to the amount of coal he fires as much as to the amount of ash and clinker he must handle. Yet how many engineers will put in a fuel with 15 per cent. ash, and expect just as good results with the same number of firemen as with a coal of 7.5 per cent. ash. The air flow has nothing to do with ash or clinker.

Mr. F. M. Van Deventer:* I would like to ask a question with regard to the permanent pressure drop through the orifice. I believe it has been stated that the restriction is so designed as to effect a differential of about 53 inches of water at the *vena contracta*. That is about two pounds per square inch. How much of that is permanently lost due to eddy currents, etc.?

Mr. E. G. Bailey: The orifice meter is designed on 53 inches of water head. The actual loss of pressure may be only a third of that differential with the orifice diameter 85 per cent.

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of the pipe diameter, because of the restoration obtained on the venturi principle. The restoration is less with a smaller ratio of orifice diameter to pipe diameter, and at 50 per cent. orifice the pressure loss is 70 per cent. of the working differential.

Mr. F. M. Van Deventer: A slide was shown of a double-outlet boiler with a duplicate installation of flow meters. It would be interesting to know something about the relative characteristics of the two charts.

Mr. E. G. Bailey: The characteristics are very similar if the piping is identical and your non-return valves are operating properly. In one plant I showed, they had a great deal of trouble with the non-return valves in the boiler—50 per cent. more steam out of one than the other. They used two meters to determine the faulty operation of those non-return valves. In plants where the piping is different you have different resistances and they never do come together; but they do show the same characteristics, so you can superpose one chart on another and they follow almost identically.

Mr. F. M. Van Deventer: Then in the case of a double-outlet boiler with identical piping from the two outlets, is the duplicate installation justified from the purchaser's point of view?

Mr. E. G. Bailey: I should recommend two, every time, because it is a lot cheaper to buy a meter than it is to burn the boiler, and if your non-return valves stick, you have more than enough trouble to justify the extra investment. I should say, never put in a double-outlet boiler.

On the question of double-outlet boilers, I took the matter up with Dr. Jacobus to get the design straightened around so we would not have to put two meters on them. He said, "You ought to be glad to sell two meters instead of one." I said, "No, because a man can get so much more value from the results if they are combined in one meter. We would rather sell one meter and get the best operating results, than sell two with less accurate results."

MR. A. STRAUB:* I would like to ask Mr. Bailey if he does not think that, with the wide furnaces that are coming into use with large boilers, it is an advantage to have two meters on the boiler to find out conditions in the combustion chamber on both sides of the furnace, as it is very difficult to maintain uniform conditions over a wide furnace by visual inspection.

MR. E. G. BAILEY: That depends on whether it is a wide furnace or a double furnace. If you have very large units it pays to split them up. We can not induce all the boiler manufacturers to change to a one-outlet equivalent, so we are now designing a new type of meter in which we can conduct the flow from each outlet into one quantity and still have the same result, and separate results for each individual outlet.

*Consulting Engineer, Pittsburgh.

COMPARATIVE ECONOMICS OF CONTINUOUS AND NON-CONTINUOUS TRUSSES

By Dr. J. A. L. Waddell* and H. Malcolm Priest†

This joint paper is the fifth in a series of 10 studies of hitherto unsolved economic problems in bridgework, undertaken by Dr. Waddell in 1916—a series which it is expected will be completed this year. It is intended to solve the last, as-yet-unsolved, major, economic problem in the specialty of bridges.

For many years past, bridge engineers have held differing opinions concerning the advantages of continuous trusses as compared with the corresponding non-continuous ones. Some claimed a great saving in weight of metal from continuity while others felt sure there was none. Dr. Waddell had the impression that the advantage claimed for the continuous truss has been due to the ignoring of the effect of reversing stresses; and, as will be seen later, in this opinion he was partly right and partly wrong.

Under certain conditions it is not bad practice to use continuous trusses, but under others it is, irrespective of the question of economics. When the foundations of the piers are solid rock or other very hard material, continuity is permissible; but when they are of piles or comparatively soft material without piles, it is better to forego any possible saving of metal rather than to run the risk of unequal settlement of piers and the consequent upsetting of stress distribution throughout the trusses from end to end of structure.

The most notable example of continuous trusses in America, or, as far as the authors know, anywhere in the world, is the Sciotoville bridge over the Ohio River on the line of the Chesapeake and Ohio Northern Railroad. At this location, continuous trusses were permissible, for the reason that the pier foundations

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†Mr. Priest joined Dr. Waddell in the work of making the numerous computations upon which this paper is based, and, therefore, is entitled to be considered a joint author; moreover, he has approved the paper as a whole.

are solid rock at no great distance below the bed of the stream. The structure consists of two continuous, double-track, railway spans of 775 feet each. It was designed and engineered by Gustav Lindenthal, C. E., and was completed in 1917.

Desiring to have this comparison of weights of metal for continuous trusses conform as closely as possible with actual conditions, the authors assumed the outlines of the Sciotoville structure, and contrasted it with a bridge of two simple-truss spans, each made five feet shorter, so as to allow for the distance between centers of pedestals on the middle pier, using practically the same panel lengths as those of the Sciotoville bridge and economic truss depths for simple-truss spans based upon the information given in Waddell's "Bridge Engineering."*

These two lay-outs are shown in Fig. 1 and 2.

The first series of computations was made upon the basis of adopting the Petit-truss type; and there was assumed a unit loading of 1,000,000 pounds, applied at one panel point at a time, the stresses therefrom being found for each main member of each span affected by the loading. These stresses were summed up for greatest tension and greatest compression on each piece, in order to determine by slide-rule the live-load stresses. The live load assumed for each track was Waddell's Class 60 loading.

In order to save time and labor, a constant percentage for impact—that given in "Bridge Engineering"—was included in the live load itself instead of varying the percentage amounts to be added to the live-load stresses in the different web members. This approximation, of course, caused certain errors in web stresses; but their effects on the two contrasted types of structure were practically alike, and, therefore, did not affect the correctness of the comparison. The reactions for concentrated loads in the continuous-truss structure were obtained by the "theorem of three moments." No attempt was made to correct, later, the stresses thus found by the more exact method of least work; for the reactions obtained in that manner by the designers of the Sciotoville bridge indicated that the difference in total weight of metal involved thereby was trifling.

*New York: Wiley. 1916.

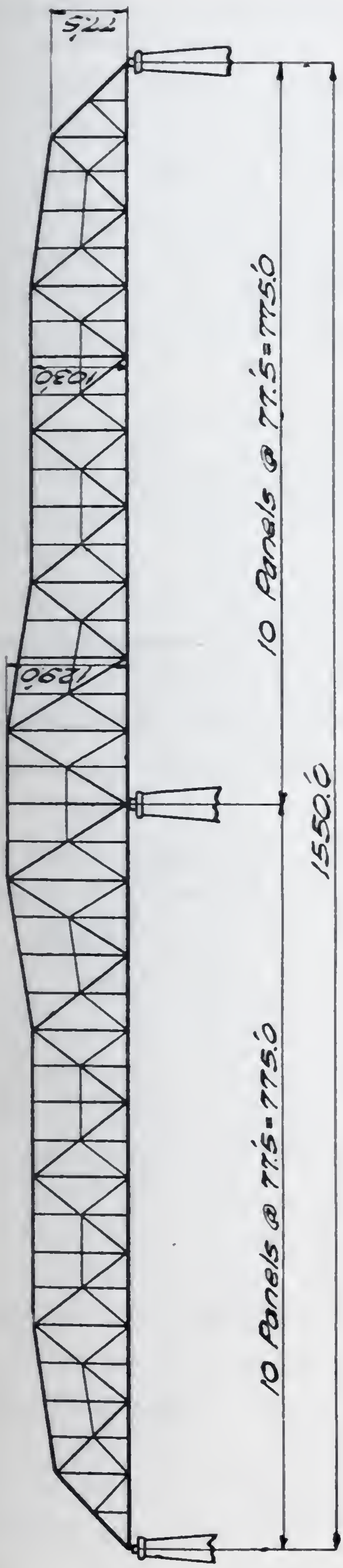

Fig. 1. Lay-Out of Subdivided-Triangular Truss, Continuous Spans.

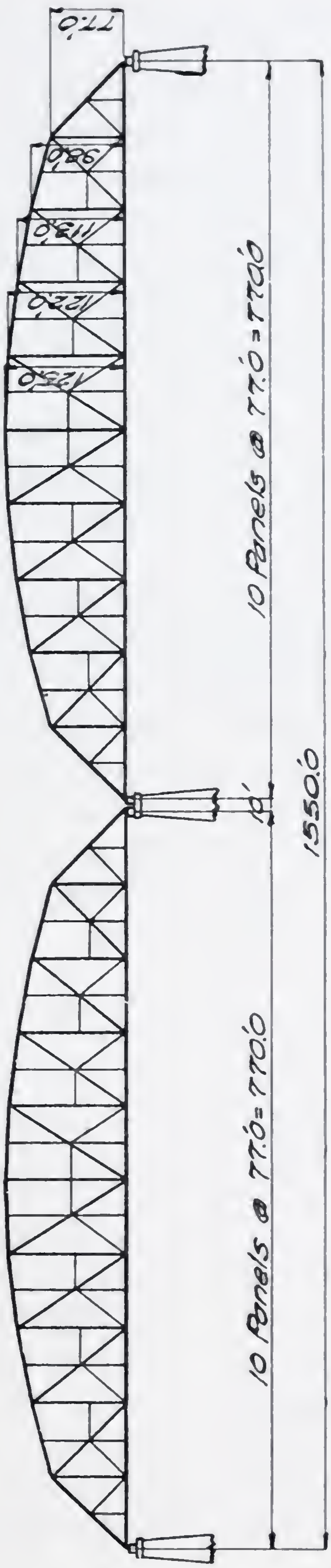

Fig. 2. Lay-Out of Petit-Truss, Non-Continuous Spans.

The finding of the live-load stresses was a comparatively simple matter, but the determining of the dead-load stresses was much more arduous, because sometimes the correct distribution of the metal between the various panel points was not ascertained until the third trial. No attention was paid to wind stresses; because, in double-track railway bridges of long span and heavy live loading, the excess intensities of working stresses allowed in modern bridge specifications for combinations of wind stresses and other stresses result in rendering wind stresses in the trusses entirely negligible.

After the live-load stresses and the dead-load stresses for both the continuous and the non-continuous spans had been computed, they were combined, and the maximum stress on each piece for both tension and compression was recorded. Then the sectional areas were determined by the specifications of chapter 78 of "Bridge Engineering," ignoring, however, all effects of reversion; after which the total weights of metal in the main members were figured for both lay-outs, and to them were added the proper percentages to cover weights of details, thus giving the comparing weights of metal for the two types of structure under consideration. Much to the authors' surprise, the weights thus found were so nearly alike that their difference amounted to a small portion of one per cent—so small, in fact, as to be negligible.

It had been intended to make an entirely new set of sectional areas and compute the resulting weights of metal for both types on the basis of caring for reversing stresses in accordance with the method provided in the before-mentioned Waddell specifications; but this was found to be unnecessary, because members in which reversion occurred were very few, and both the direct and the indirect effects thereof were readily determined. By "indirect" effect is meant, in this case, the increase in weight of metal due to augmentation of the dead load caused by provision for reversal. Here again was a surprise, for the effects on the two types were exactly alike. These computations showed that, for long-span, double-track, steam-railway bridges of the Petit-truss type, there is no economy of metal whatsoever in making adjacent spans continuous over the piers, and that the matter of caring for or ignoring

the effects of reversing stresses does not in any way influence the economics.

These results were so decided, and the coincidence of weights was so exact, that at first the authors thought the entire question was settled; but it was suggested by Mr. Shortridge Hardesty, Dr. Waddell's designing engineer, that, if the divided-triangular truss adopted for the Sciotoville bridge were investigated, a different result might be found. It was decided, therefore, to make the test. The lay-outs of trusses for the new comparison are shown in Fig. 3 and 4. The computations were all prepared exactly as before, and it was found necessary to make two sets of figures for the continuous-truss lay-out before the correct dead load was determined. The findings of this second set of computations were as follows.

In the simple-truss spans the weights of metal for the divided-triangular and the Petit types were nearly alike, the slight existing difference being in favor of the former; and the continuous-truss type showed a gain of 12 per cent. over the non-continuous type when reversion was ignored, and 11 per cent. when proper provision was made for it.

The computations made, up to this stage of the investigation, settled the economics for long-span, steam-railway bridges; but it was seen by *a priori* reasoning that the results would probably be somewhat different for standard highway bridges; consequently, it was decided to repeat the calculations for the latter structures. To this end the total loadings—i. e., live load plus dead load—were retained, but a different division thereof was made by diminishing the live loads and increasing the dead loads, so as to correspond, as nearly as may be, with the actual live-load and dead-load ratio in modern highway bridges with paved roadway, reinforced-concrete base slab, and reinforced-granitoid sidewalks for the span length under consideration.

The result of this third set of computations showed that for the divided-triangular-truss lay-out there was an economy of 22 per cent. in favor of the continuous trusses, and that reversing stresses affected very few members, and those so slightly that the influence of reversion could be completely ignored. It was not

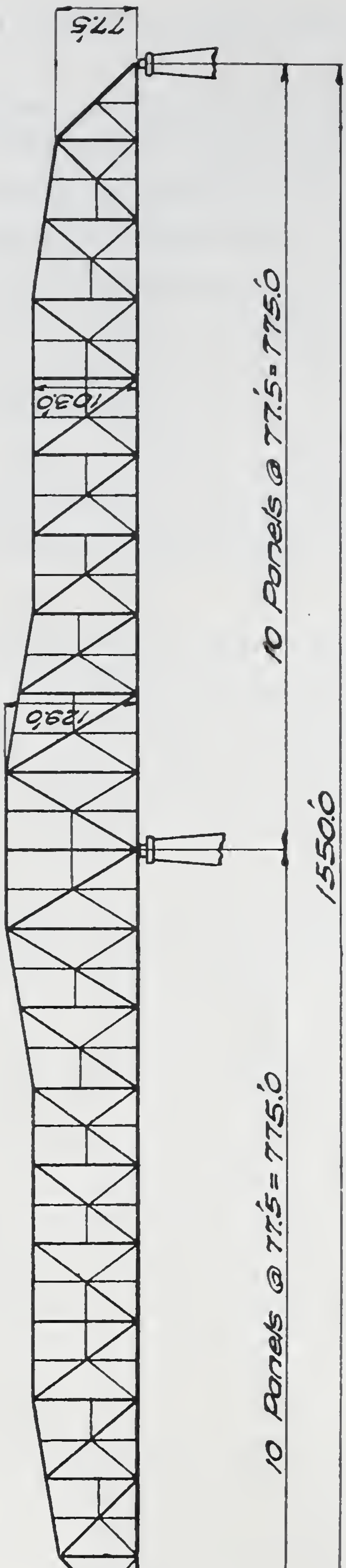

Fig. 3. Lay-Out of Petit-Truss, Continuous Spans.

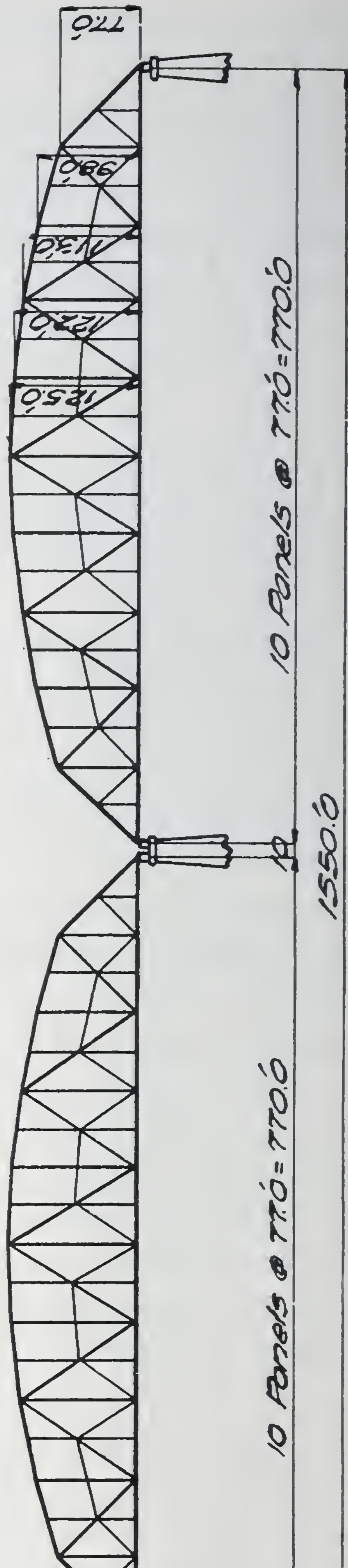

Fig. 4. Lay-Out of Subdivided-Triangular Truss, Non-Continuous Spans.

thought worth while to repeat these highway bridge calculations for the Petit-truss lay-outs.

The computations made, thus far, settled the comparative economics of continuous and non-continuous trusses for long-span bridges, both railway and highway—also those of the Petit and the divided-triangular trusses for such structures—but it could not properly be assumed that what was found to be true for long spans would apply also to short ones; consequently, it was decided to make a new set of computations for comparatively short-span lay-outs for steam-railway bridges of both the divided-triangular-truss and the Pratt-truss types.

By reducing all the truss dimensions to one half, it was practicable to employ, without change, the previously determined index stresses (those found from assumed unit loadings), and thus the labor of figuring was greatly reduced. As before, the dead-load stress computations were repeated until the assumed and resulting dead loads at the different panel points were in close agreement. The results of this fourth set of calculations were as follows.

The divided-triangular-truss figures indicated a gain of seven per cent. for the continuous-truss lay-out over the non-continuous one when reversing stresses were ignored, and *no gain at all but simply a stand-off* when proper provision was made for them; but when the Pratt truss was employed, the non-continuous truss lay-out showed a gain of two per cent. over the continuous truss lay-out when reversing stresses were ignored and five per cent. when they were properly provided for.

The said results also indicated for short, simple-truss spans that, when reversals are ignored, there is no difference in weight of metal between steam-railroad bridges of the Pratt-truss and the divided-triangular-truss types; but that, when reversals are properly provided for, the latter has an advantage of five per cent.

It was not deemed worth while to compute the economics for highway bridges of short spans; but it might be inferred by *a priori* reasoning, based on the preceding results, that, in the case of the divided-triangular trussing, the continuous spans would have an advantage of 13 per cent. when reversals are ignored and 12 per cent. when they are properly cared for; also that, in the

case of the Pratt trussing, there would be no material advantage in continuity for either of the contrasted types under any consideration.

Without making another set of computations, the authors would not care to employ *a priori* reasoning for the determination of the comparative economics of continuous and non-continuous trusses in long-span, highway bridges of the Petit-truss type, excepting that it seems pretty safe to assume that the Petit trussing would have no advantage over the divided-triangular trussing, and that the continuous trusses would probably show a small advantage over the non-continuous ones.

All the actual results of the calculations made for this memoir are collected in the two following tables, and are expressed in ratios, unity standing for weights of continuous trusses of the divided-triangular type when the effect of reversion is ignored.

SUMMARY OF WEIGHT RATIOS

DIVIDED-TRIANGULAR TRUSSING

Span-length in feet	Type of bridge	Reversals ignored Continuous	Reversals ignored Simple	Reversals considered Continuous	Reversals considered Simple
775	Railway	1.00	1.12	1.03	1.14
775	Highway	1.00	1.22	1.00	1.22
387.5	Railway	1.00	1.07	1.10	1.10

PETIT OR PRATT TRUSSING

Span-length in feet	Type of bridge	Reversals ignored Continuous	Reversals ignored Simple	Reversals considered Continuous	Reversals considered Simple
775	Railway	1.13	1.13	1.16	1.16
387.5	Railway	1.09	1.07	1.20	1.15

SUMMARY OF CONCLUSIONS

Summarizing the results of the entire investigation, the following conclusions are reached:

1. For long spans the divided-triangular trussing is decidedly superior to the Petit trussing for bridges with continuous-truss spans; but not much so, if at all, for those of simple-truss spans.

2. For long spans there is an important saving of metal by the adopting of continuous trusses, and this saving is nearly twice

as great for standard highway bridges as for modern, double-track railway bridges.

3. For long-span bridges the method of treating the matter of stress reversal has practically no effect upon the comparative economics of continuous and non-continuous trusses.

4. For comparatively short-span, steam-railway bridges, the continuous truss has a slight advantage over the simple truss, only when the divided-triangular trussing is used and stress reversals are ignored. In all other cases, the comparison is either a stand-off or in favor of the simple trusses.

5. For comparatively short-span, steam-railway bridges, the divided-triangular trussing is generally more economical of metal than the Pratt trussing.

6. In no case should either the Pratt or the Petit truss be employed for continuous spans, because in these the divided-triangular truss is more economical.

COMPARATIVE ECONOMICS OF WIRE CABLES AND HIGH-ALLOY-STEEL EYE-BAR CABLES FOR LONG-SPAN SUSPENSION BRIDGES

By Dr. J. A. L. Waddell*

The economic comparison of wire cables and eye-bar cables for suspension bridges has never before been brought to the attention of American engineers, for the reason that comparatively few structures of the suspension type have been built in this country. Their unsuitability for railway bridges, excepting those of exceedingly long span—far longer than any that have been constructed—and the slow development of the American highway system have combined to keep the type in the background; but the time is approaching when it will be necessary to carry our rapidly developing network of highways across some of the largest of our rivers, and then the suspension bridge may have an opportunity to come into its own. It must not be forgotten, however, that the conditions warranting the building of a suspension bridge are not likely to be often encountered; because it is nearly always the fiat of the War Department which necessitates a span length so great as to render economical the building of a structure of that type.

By means of a long and elaborate economic investigation made in 1918 and published in 1919 by the Western Society of Engineers under the caption "Comparative Economics of Cantilever and Suspension Bridges," the author has shown the span lengths of equal cost for these two classes of structure. The said lengths usually vary from 1000 feet for highway bridges to about 2600 feet for steam-railway bridges, the lengths for combined steam-railway and highway structures being intermediate and directly interpolated in accordance with the division of total live load, including impact allowances, between railways and highways. Later, it was found that the irregularity of the abnormal unit prices of materials, at present prevailing, has lengthened the spans of equal cost some two hundred feet for highway bridges

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and sixty feet for steam-railway bridges; but a return to normal market conditions will assuredly bring them back to about the limits first found.

Had the original investigation been based upon the assumption of anchored ends instead of free ends for the stiffening trusses, the span lengths for equal cost would have been found about one hundred feet shorter, or 900 feet for highway bridges and 2500 feet for railway bridges at *ante-bellum* unit prices, and 1100 feet for highway bridges and 2560 feet for railway bridges at the unit prices prevailing early in 1920.

As that investigation proved that the suspension bridge is less economical for steam-railway traffic than the cantilever structure, up to the extreme practicable main-span length of the latter, and as it is well known that the cantilever is always the superior of the two in respect to the important matter of rigidity, the present investigation has been limited to the consideration of highway bridges carrying also electric-railway trains, such as those that cross the East River in New York City.

The comparative advantages and disadvantages of the two types of cables are as follows:

1. The wires for the cables have higher elastic limit and ultimate strength than can probably ever be developed in eye-bars.

2. The percentage of weight of details is far lower for wire cables than for eye-bar cables.

3. The cost of erection is inevitably less for wire cables than for eye-bar cables because with the former, the process, while tedious, is not at all complicated. Before the erection of the eye-bar chains is begun, it is necessary to string across from anchorage to anchorage and over the tower tops several lines of small wire cables. These have to be used in order to carry the first few lines of bars until the latter can be made self-supporting; and although there will, of course, be some salvage on such erecting cables, their use will be quite expensive. Again, as the eye-bars will have to be placed on the pins by heating and shrinking, it is evident that the process will necessarily be a slow one, requiring considerable apparatus; hence the erection cost will run high. The total cost of erection, therefore, is larger for the eye-bar cables

not only because of the higher unit cost of manipulation but also on account of the greater weight of metal to be put in place.

4. The lowest point in the catenary of the wire cables can be located very close to the top surface of the deck, thus making the height and the cost of the tower columns a minimum. Owing to the necessity for keeping the bottom chords of the crescent trusses above the elevation of the floor, and because, for a fair comparison, the center-lines of the pairs of eye-bar cables must coincide with those of the wire cables, it is necessary to raise the tops of the towers several feet, thus increasing not only the cost of the latter but also the length and cost of the backstays.

5. Wire cable bridges do not call for special wind chords for the lateral system; but in eye-bar cable bridges, owing to the omission of special stiffening trusses, it is necessary to provide such chords, and this item is likely to be quite expensive.

6. The pound price of the wire cables is comparatively high, being at present about twice as great as that for eye-bar cables of nickel steel.

7. The attachment of the wires at the anchorages is both tedious and expensive, whilst that of the eye-bars is simple and expeditious.

8. The wire cables require stiffening trusses; but the two tiers of eye-bar cables are in tension under all conditions of loading; and hence they can serve, without stiffening, as the compression chords of the crescent trusses which are formed by the addition to them of vertical posts and adjustable diagonals.

9. There is an uncertainty in respect to stress distribution in the stiffening trusses of the wire cable bridge that does not exist in the eye-bar cable structure, although, strictly speaking, the adjustable diagonals in the latter involve a small amount of ambiguity in the division of the shear. All stresses in the eye-bar cable bridges can be determined with accuracy by the established principles of statics, whilst those in the stiffening trusses of wire cable bridges are found approximately by several different theories based upon assumptions which are sometimes of more than doubtful accuracy; and, consequently, considerable uncertainty concerning the maximum stresses to be provided for is involved.

To as great an extent as practicable, all of these governing

conditions have been duly considered in making the economic studies for the preparation of this memoir.

When the lay-out of the investigation for the solution of the economic problem herein discussed was first considered, it was intended to make the said investigation comparatively short by confining it to spans of only one length and having but one live load. That span length was 1750 feet—selected because it was used by the author in his preliminary study of the proposed crossing of the Delaware River between Philadelphia and Camden, N. J., made for the Camden Bridge Commissioners.

The proposed structure consisted of a single suspension span with backstays, the approaches to it being either steel or reinforced concrete trestlework, entirely independent of the main span. The deck, in a later modification, was laid out for a double-track electric railway at the middle, a paved roadway supported by a reinforced-concrete base 22 feet wide in the clear on each side thereof, and two sidewalks, each 10 feet wide, cantilevered beyond the trusses, of which there were four lines. In the first design each of these trusses consisted of two eye-bar cables forming two crescents each with a web system between, composed of vertical posts and adjustable tension diagonals; but, later, there was also figured a wire cable structure with stiffening trusses. In each case the towers consisted of braced steel columns with segmental-roller pedestals resting on concrete shafts supported by pneumatic caissons sunk to bed-rock at a depth of about one hundred feet below low water. The anchorages were to be of plain concrete either supported by piles driven to bed-rock or else resting directly on a foundation of satisfactorily hard material, should such be encountered when making the borings. Fig. 1 gives the lay-out for the wire cable type, and Fig. 2 that for the eye-bar cable.

The first set of calculations prepared for this paper was based on the preceding data and consisted of five designs and estimates of cost of finished bridge upon the following lines:

1. Wire cables of very high elastic limit and ultimate strength.

2. Mayarí-steel, eye-bar cables having an elastic limit of 50,000 pounds per square inch and an ultimate strength of 85,000 pounds per square inch.

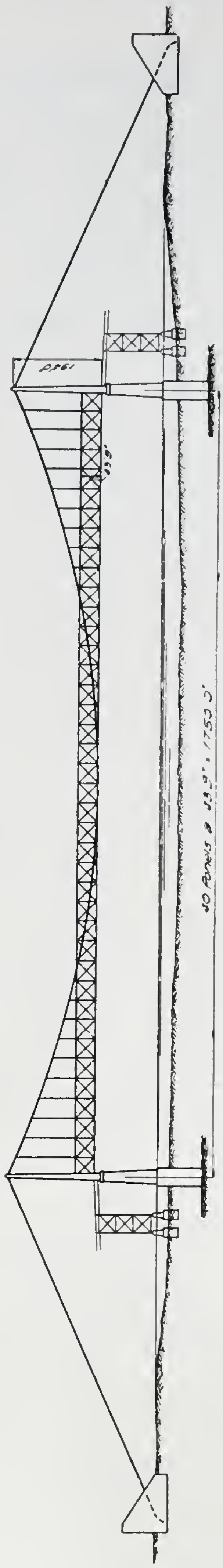

Fig. 1. Lay-Out of Wire Cable Suspension Bridge.

Fig. 2. Lay-Out of Eye-Bar Cable Suspension Bridge.

3. High-grade, nickel-steel, eye-bar cables having an elastic limit of 60,000 pounds per square inch and an ultimate strength of 100,000 pounds per square inch.

4. Heat-treated, alloy-steel, eye-bar cables having an elastic limit of at least 75,000 pounds per square inch and an ultimate strength of 115,000 pounds per square inch.

5. Heat-treated, alloy-steel, eye-bar cables having an elastic limit of at least 100,000 pounds per square inch and an ultimate strength of 150,000 pounds per square inch.

The specifications used for the designing, as far as they would apply, were those given in chapter 78 of the author's "Bridge Engineering,"* and the intensities of working stresses for the cables were 60,000 pounds per square inch for wire, and either one-half of the elastic limit or one-third of the ultimate strength for eye-bars, the lower of the two values being adopted. The material for stiffening trusses, webs of crescent trusses, floor system, lateral systems, towers, and anchorages was assumed to be commercial nickel steel, having an elastic limit of 55,000 pounds per square inch and an ultimate strength of 90,000 pounds per square inch.

The live loads employed were as follows:

For the floor system, Class 25 for the electric railway; Class B for the roadways; and Class C for the side-walks.

For the trusses, a logical combination of these loads was adopted; and a 10-car subway train was assumed on each track when figuring the stiffening trusses of the wire cable structure and the crescent trusses of the eye-bar cable structure. When finding the moments and shears for the former, in order to give the wire cable bridge the best possible chance to compete, the ends of its stiffening trusses were assumed to be anchored down, although, of course, not fixed, and the theory of stress determination adopted was the approximate method given in Johnson, Bryan, and Turneaure's "Modern Framed Structures," part 2,† instead of the older method of Dr. William H. Burr, which, for convenience and simplicity, was taken as standard by the author in

*New York: Wiley. 1916.
†Ed. 9, p. 212. New York: Wiley. 1910.

writing chapter 27 of "Bridge Engineering." The results of the two theories do not differ greatly, especially for ends of trusses anchored, but the later theory requires a little less metal.

In order to ascertain the weights of metal in the crescent trusses, there was assumed for each panel point a load of unity, and its effect was computed for every web member and every chord member thereof, thus rendering it easy to find all the live-load stresses and dead-load stresses by means of the slide-rule. These index stresses were checked by an independent computer.

After the first set of computations was completed, the question arose as to whether the assumption of a double-deck structure carrying a much greater proportion of electric-railway live load would have caused any material changes in the results; and it was decided to repeat the calculations for a set of five double-deck structures. The result indicated no serious disagreement, as is shown by the following table.

TABLE I. RATIO OF QUANTITIES OF MATERIALS IN EYE-BAR CABLE BRIDGES TO THOSE IN WIRE CABLE BRIDGES

Elastic limits of eye-bars	Ratios of quantities							
	Cables		Nickel steel		Anchorages and Pier shafts		Pier bases	
	Single deck	Double deck	Single deck	Double deck	Single deck	Double deck	Single deck	Double deck
50,000	3.76	3.75	0.73	0.69	1.09	1.08	1.16	1.15
60,000	2.82	2.82	0.68	0.66	1.03	1.02	1.06	1.08
75,000	2.05	2.05	0.65	0.62	0.99	0.98	1.00	0.96
100,000	1.42	1.41	0.63	0.60	0.94	0.93	1.00	0.88

An analysis of this table shows how very little variation there is between single-deck and double-deck bridges in respect to the proportions of the various materials in wire cable structures and the corresponding eye-bar cable structures. For this reason, in what follows, the author, with a clear conscience, has drawn his general conclusions from computations on single-deck structures only, thus saving considerable time and expense. His so doing is a good illustration of the application of the "economics of bridgework" which he is endeavoring to expound.

The investigations made up to this point permitted the establishment of a number of formulæ for quantities of materials involving variations in span length and loading, thus permitting of

an extension of the study without a seriously great augmentation of labor and expense. These formulæ are strictly logical in form. They were derived on a theoretical basis, the coefficients thus determined being changed a few per cent., where necessary, to agree with the computed weights for the various structures which had been worked out completely. It was, therefore, decided to compute and record quantities for shorter and longer spans in order to prepare curves giving, for all practicable span lengths, the quantities of all materials *per lineal foot of main span.*

The formulæ referred to are the following:

WIRE CABLE BRIDGES

STIFFENING TRUSSES OF MAIN SPAN

Weight of one chord.

Effect of live-load reversal neglected:

$$W_c = 0.09 \frac{Ll^2}{sd}\left(0.8 + 4\frac{wd}{Lt}\right), \text{ but not } < 0.09\frac{Ll^2}{sd}.$$

Fifty per cent. of reversal stress added to main stress:

$$W_c = 0.12 \frac{Ll^2}{sd}\left(0.9 + 1.5\frac{wd}{Lt}\right), \text{ but not } < 0.12\frac{Ll^2}{sd}.$$

Seventy-five per cent. of reversal stress added to main stress:

$$W_c = 0.132 \frac{Ll^2}{sd}\left(0.92 + 1.1\frac{wd}{Lt}\right), \text{ but not } < 0.132\frac{Ll^2}{sd}.$$

Weight of web members.

Pratt system.

Effect of live-load reversal neglected:

$$W_w = 0.83 \frac{Ll}{s}\left(\frac{p^2 + 2d^2}{dp}\right) = 2.5 \frac{Ll}{s} \text{ for } p = d.$$

Fifty per cent. of reversal stress added to main stress:

$$W_w = 1.25 \frac{Ll}{s}\left(\frac{p^2 + 2d^2}{dp}\right) = 3.75 \frac{Ll}{s} \text{ for } p = d.$$

Seventy-five per cent of reversal stress added to main stress:

$$W_w = 1.46 \frac{Ll}{s}\left(\frac{p^2 + 2d^2}{dp}\right) = 4.38 \frac{Ll}{s} \text{ for } p = d.$$

Warren system, single or double cancelation, with verticals.

Effect of live-load reversal neglected:

$$W_w = 0.83 \frac{Ll}{s} \left(\frac{p^2 + 1.5\ d^2}{dp}\right) = 2.1 \frac{Ll}{s} \text{ for } p = d.$$

Fifty per cent. of reversal stress added to main stress:

$$W_w = 1.25 \frac{Ll}{s} \left(\frac{p^2 + 1.5\ d^2}{dp}\right) = 3.12 \frac{Ll}{s} \text{ for } p = d.$$

Seventy-five per cent of reversal stress added to main stress:

$$W_w = 1.46 \frac{Ll}{s} \left(\frac{p^2 + 1.5\ d^2}{dp}\right) = 3.65 \frac{Ll}{s} \text{ for } p = d.$$

Notation.

l = Main span length in feet.
d = Depth of stiffening truss in feet.
p = Panel length of stiffening truss in feet.
t = Transverse distance between chords carrying wind stresses.
L = Live load in pounds per lineal foot of truss.
w = Transverse wind load, in pounds per lineal foot of bridge, on lateral system in plane of chord under consideration.
s = Working stress in tension, in pounds per square inch.
W_c = Weight of one chord in pounds per lineal foot.
W_w = Weight of web members, in pounds per lineal foot of truss.

MAIN CABLES

Weights.

$$W = \frac{0.45\ l^2 \sec B}{rS - 0.45\ l^2 \sec B \dfrac{l'}{l}} (D_s + \mathrm{L}) =$$

$$\frac{0.45\ ll' \sec B}{rS - 0.45\ ll' \sec B} (D_s + \mathrm{L}).$$

$$W \frac{l'}{l} = \frac{0.45\ l^2 \sec B \dfrac{l'}{l}}{rS - 0.45\ l^2 \sec B \dfrac{l'}{l}} (D_s + \mathrm{L}) =$$

$$\frac{0.45\ l^2 \sec B}{rS - 0.45\ ll' \sec B} (D_s + \mathrm{L}).$$

For $\frac{r}{l} = \frac{1}{9}$, sec $B = 1.094$, $\frac{l'}{l} = 1.032$.

$$W = \frac{4.4\,l}{S - 4.55\,l}\,(D_s + \text{L}).$$

$$W\frac{l'}{l} = \frac{4.55\,l}{S - 4.55\,l}\,(D_s + \text{L}).$$

Notation.

l = Main span length in feet.
l' = Length of cable of central span in feet.
r = Rise of cable in feet.
B = Angle of inclination of cable at tower.
D_s = Superimposed dead load in pounds per lineal foot of bridge (exclusive of weight of cable).
L = Live load in pounds per lineal foot of bridge.
S = Working tensile stress in cable, in pounds per square inch.
W = Weight of cable in pounds per foot of cable.
$W\frac{l'}{l}$ = Weight of cable in pounds per lineal foot of bridge, for main span only.

EYE-BAR CABLE BRIDGES, FOR $\frac{r}{l} = \frac{1}{9}$ ONLY

Weight of eye-bars in main span:

$$W_e = \frac{5.2\,l}{S - 5.2\,l}\left[D_s + L\left(0.4 + \frac{3\,l}{100\,d}\right)\right].$$

Weight of web members of cable:

$$W_w = 1.7\,\frac{Ll}{S}\left(0.8 + 0.2\,\frac{d^2}{p^2}\right), \text{ but not } < 1.7\,\frac{Ll}{S}.$$

Notation.

l = Length of main span in feet.
r = Rise of cable in feet.
d = Maximum depth of crescent truss in feet.
p = Panel length of crescent truss in feet.
D_s = Superimposed dead load in pounds per lineal foot of bridge (exclusive of weight of eye-bars, but including weight of web members of cable).

L = Live load in pounds per lineal foot of bridge.
S = Working stress in tension in pounds per square inch.
W_e = Weight of eye-bars in pounds per lineal foot of bridge.
W_w = Weight of web members of crescent truss, in pounds per lineal foot of bridge.

The span length selected for the low limit of the computations was 1200 feet, and that for the high limit thereof was 2300 feet, thus giving for all diagrams three points through which to pass each curve. Ordinarily, it is not safe to plot a curve through three points only; but, in this case, there were at hand a number of similar curves for suspension bridges previously established by the author for another economic investigation, hence no mistake was made in the plotting.

The results of the computations are shown in Fig. 3–5.

In Fig. 3 are recorded on four separate diagrams the quantities of the various materials for wire cable bridges of span lengths varying from 1000 to 3000 feet. The curves are for single-deck structures; but the quantities found for the double-deck structures of 1750 feet span are shown by short dotted lines. In Fig. 4 are indicated in a similar manner the weights of metal per lineal foot of main span for alloy-steel eye-bars in bridges of that type; and in Fig. 5 are recorded, correspondingly, the quantities of nickel steel, concrete in shafts and anchorages, and mass of materials in pier bases for such structures.

In order to illustrate the manner of using these diagrams, and at the same time to draw therefrom conclusions concerning the present status of the economics of the two types of cable under discussion, it will be well to solve several examples based on current unit prices of the materials in place. These may be taken as follows:

Wire cables	23 cents per pound.
Mayarí steel	10 cents per pound.
Commercial nickel steel	11 cents per pound.
High-grade nickel steel	12 cents per pound.
Concrete in pier shafts and anchorages	$16.00 per cubic yard.
Mass of pneumatic bases	$35.00 per cubic yard.

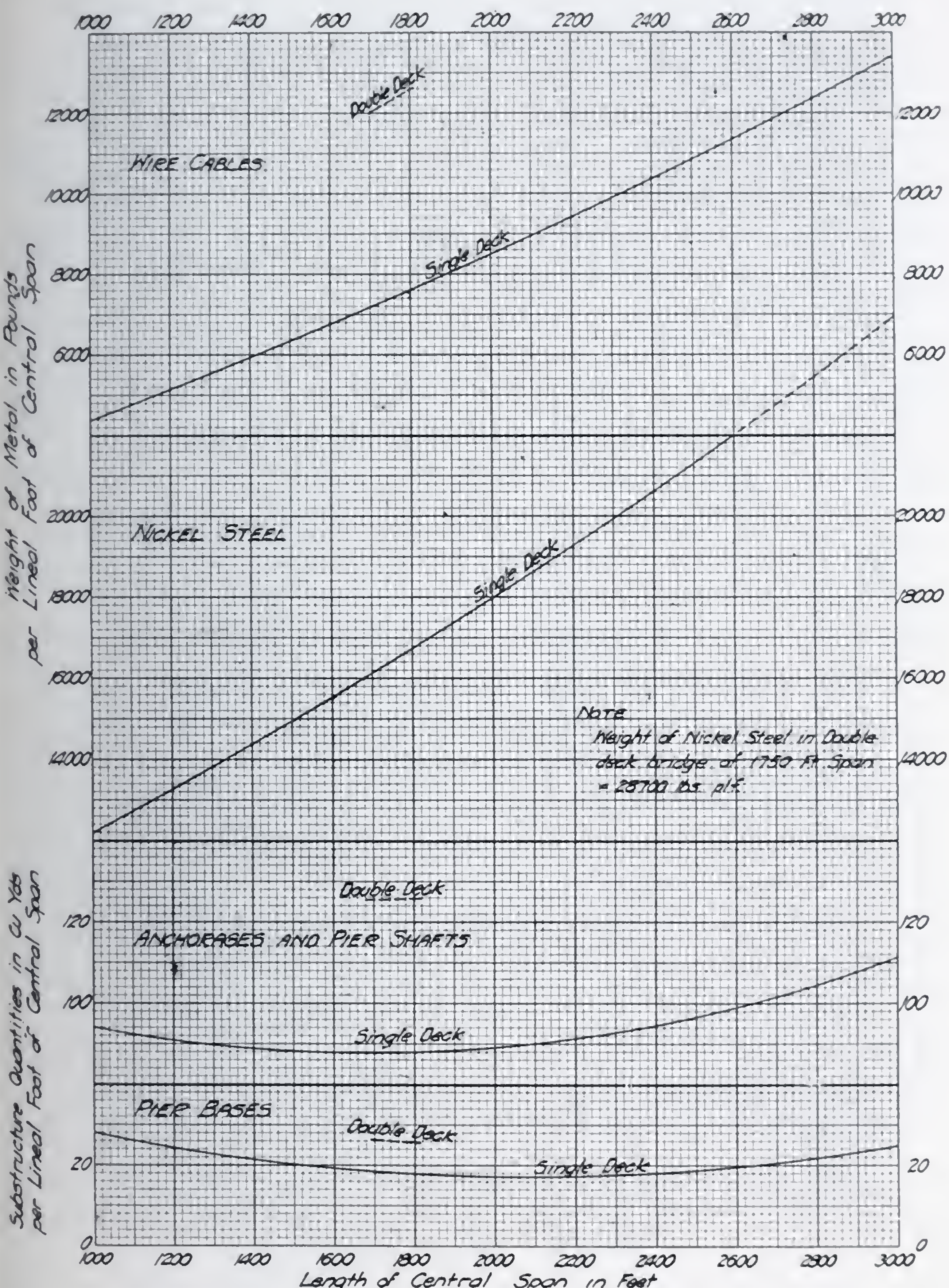

Fig. 3. Quantities for Wire Cable Suspension Bridges.

In pitting the eye-bar cables of the various alloy steels against wire cables it will suffice to figure for three spans; viz., those of 1000, 2000, and 3000 feet. Attention is called to the fact that the costs found per foot of main span are not total for the structures,

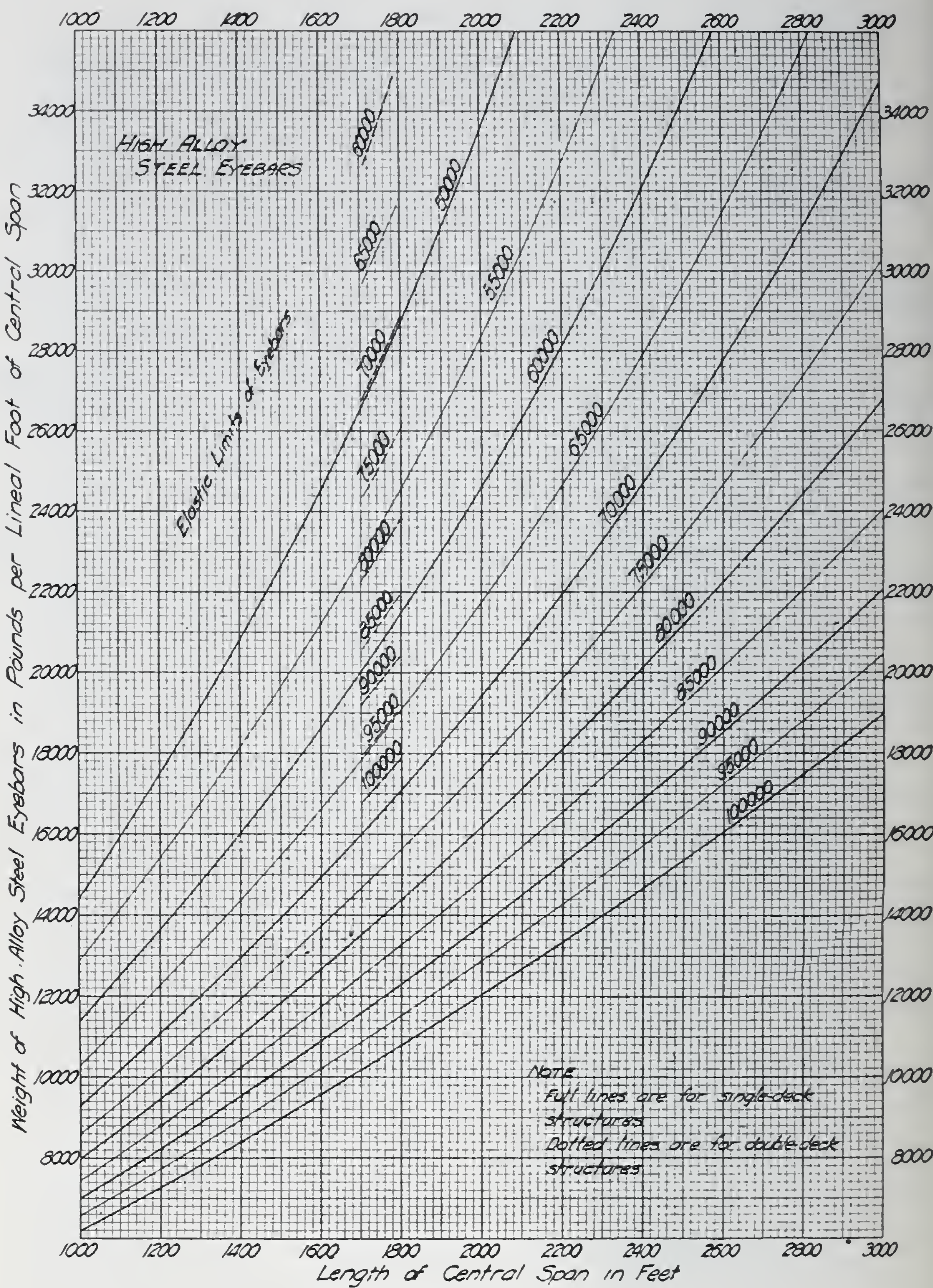

Fig. 4. Quantities for Eye-Bar Cable Suspension Bridges.

because the items of costs of deck and floor system, being the same for both types, have been omitted for the sake of simplicity. The lateral system, though, has been taken into account, because the weights of metal thereof in the two types of structure differ mate-

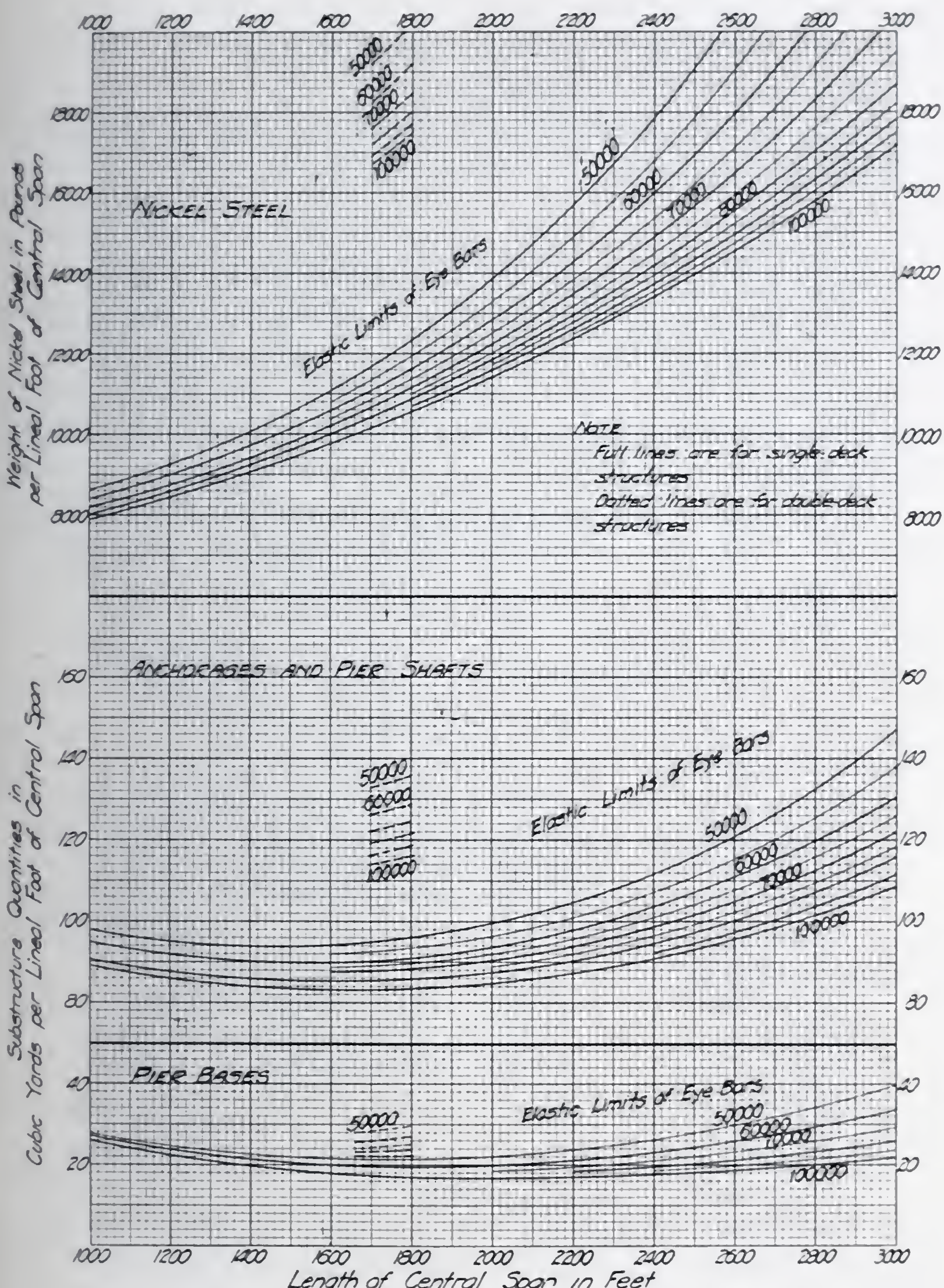

Fig. 5. Quantities for Eye-Bar Cable Suspension Bridges.

rially. The principal reason for this is that, in the eye-bar type, special wind chords will be required; whilst, in the wire cable type, the chords of the stiffening trusses serve as wind chords, only a small increase in sections above those needed for live loads being required.

MAYARÍ STEEL COMPARISON

1000-FOOT SPAN

From Fig. 3 we can make for the wire cable structure the following estimate:

Wire cables	4,300 pounds at 23 cents	=	$ 989.00
Nickel steel	12,200 pounds at 11 cents	=	1,342.00
Plain concrete	94 cubic yards at $16.00	=	1,504.00
Mass of bases	28 cubic yards at $35.00	=	980.00
	Total	=	$4,815.00

From Fig. 4 and 5 we have for the Mayarí steel the following estimate:

Mayarí steel	14,400 pounds at 10 cents	=	$1,440.00
Nickel steel	8,600 pounds at 11 cents	=	946.00
Plain concrete	98 cubic yards at $16.00	=	1,568.00
Mass of bases	28 cubic yards at $35.00	=	980.00
	Total	=	$4,934.00

2000-FOOT SPAN

Wire Cable Structure

Wire cables	8,500 pounds at 23 cents	=	$1,955.00
Nickel steel	18,000 pounds at 11 cents	=	1,980.00
Plain concrete	89 cubic yards at $16.00	=	1,424.00
Mass of bases	17 cubic yards at $35.00	=	595.00
	Total	=	$5,954.00

Eye-bar Cable Structure

Mayarí steel	33,600 pounds at 10 cents	=	$3,360.00
Nickel steel	13,800 pounds at 11 cents	=	1,518.00
Plain concrete	100 cubic yards at $16.00	=	1,600.00
Mass of bases	22 cubic yards at $35.00	=	770.00
	Total	=	$7,248.00

From these four estimates it is evident that at present prices untreated Mayarí-steel eye-bar cables cannot compete with wire cables in suspension bridges. With the shortest economic span length for highway suspension bridges—1000 feet—in order to compete with wire, the untreated Mayarí steel would have to be put in place at a pound price of less than 9.2 cents. While this could probably be done without actual loss, it can readily be seen that, in general, untreated Mayarí-steel eye-bars cannot be employed economically for suspension-bridge cables.

As heat-treated, carbon-steel eye-bars have an elastic limit of 50,000 pounds per square inch, the same as that for untreated Mayarí-steel eye-bars, and as the unit price erected is also about the same, the conclusions reached concerning the latter will apply also to the former.

As for heat-treated, Mayarí-steel eye-bars, the author has no data regarding their strength, nor is he convinced that the irregularity in the elastic limit of that alloy would not militate too strongly against using it in bridgework after heat treatment. Judging, though, from the computations which follow concerning heat-treated, nickel-steel eye-bars, one would surmise that suspension bridges of heat-treated, Mayarí-steel eye-bars might be economical up to spans of 2000 feet.

HIGH-GRADE NICKEL-STEEL COMPARISON

1000-FOOT SPAN

Eye-bar Cable Structure

Eye-bar cables	11,400 pounds at 12 cents	=	$1,368.00
Nickel steel	8,300 pounds at 11 cents	=	913.00
Plain concrete	94 cubic yards at $16.00	=	1,504.00
Mass of bases	27 cubic yards at $35.00	=	945.00
	Total.....	=	$4,730.00

2000-FOOT SPAN

Eye-bar Cable Structure

Eye-bar cables	24,600 pounds at 12 cents	=	$2,952.00
Nickel steel	12,800 pounds at 11 cents	=	1,408.00
Plain concrete	94 cubic yards at $16.00	=	1,504.00
Mass of bases	20 cubic yards at $35.00	=	700.00
	Total.....	=	$6,564.00

A comparison of these figures with those previously made for wire cable structures shows that the high-grade, untreated, nickel steel is economic for 1000 foot spans but not for those of 2000 feet, hence let us test for an intermediate length.

1500-FOOT SPAN

Wire Cable Structure

Wire cables..........	6,400 pounds at 23 cents	=	$1,472.00
Nickel steel..........	15,000 pounds at 11 cents	=	1,650.00
Plain concrete........	88 cubic yards at $16.00	=	1,408.00
Mass of bases........	20 cubic yards at $35.00	=	700.00
	Total.....	=	$5,230.00

Eye-bar Cable Structure

Eye-bar cables.......	17,300 pounds at 12 cents	=	$2,076.00
Nickel steel..........	10,100 pounds at 11 cents	=	1,111.00
Plain concrete........	90 cubic yards at $16.00	=	1,440.00
Mass of bases........	20 cubic yards at $35.00	=	700.00
	Total.....	=	$5,327.00

From these figures it is seen that untreated, high-grade, nickel-steel eye-bars can compete to-day with wire cables for span lengths below about 1400 feet. If they were heat-treated, their intensities of working stress could probably be made as high as 40,000 pounds per square inch, corresponding to an elastic limit of 80,000 pounds or an ultimate strength of 120,000 pounds. The value of these eye-bars in place would be 13 cents per pound.

HEAT-TREATED NICKEL-STEEL COMPARISON

2000-FOOT SPAN

Eye-bar Cable Structure

Eye-bar cables.......	16,100 pounds at 13 cents	=	$2,093.00
Nickel steel..........	11,900 pounds at 11 cents	=	1,309.00
Plain concrete........	87 cubic yards at $16.00	=	1,392.00
Mass of bases........	18 cubic yards at $35.00	=	630.00
	Total.....	=	$5,424.00

This is considerably less than the cost previously found for a wire cable structure, consequently let us test for a 2500 foot span.

2500-FOOT SPAN

Wire Cable Structure

Wire cables..........	10,800 pounds at 23 cents	=	$2,484.00
Nickel steel..........	21,400 pounds at 11 cents	=	2,354.00
Plain concrete........	97 cubic yards at $16.00	=	1,552.00
Mass of bases........	19 cubic yards at $35.00	=	665.00
	Total.....	=	$7,055.00

Eye-bar Cable Structure

Eye-bar cables.......21,000	pounds at 13 cents	=	$2,730.00
Nickel steel..........14,800	pounds at 11 cents	=	1,628.00
Plain concrete........98	cubic yards at $16.00	=	1,568.00
Mass of bases........20	cubic yards at $35.00	=	700.00
	Total.....	=	$6,626.00

From these assumed figures it appears that heat-treated, high-grade, nickel-steel eye-bars could be used economically for suspension-bridge spans up to at least 3000 feet.

It is within the realm of possibility that in a few years there will be manufactured heat-treated, chrome-molybdenum-steel eye-bars having an ultimate strength of 150,000 pounds per square inch, for which the intensity of working stress may be taken at 50,000 pounds per square inch, corresponding to minimum elastic limit of 100,000 pounds; and that the metal in place will be worth not to exceed 15 cents per pound.

Let us test this for a 3000-foot span.

HEAT-TREATED CHROME-MOLYBDENUM-STEEL COMPARISON

3000-FOOT SPAN

Wire Cable Structure

Wire cables..........13,400	pounds at 23 cents	=	$3,082.00
Nickel steel..........25,000	pounds at 11 cents	=	2,750.00
Plain concrete.......112	cubic yards at $16.00	=	1,792.00
Mass of bases........25	cubic yards at $35.00	=	875.00
	Total.....	=	$8,499.00

Eye-bar Cable Structure

Eye-bar cables.......19,000	pounds at 15 cents	=	$2,850.00
Nickel steel..........17,200	pounds at 11 cents	=	1,892.00
Plain concrete.......110	cubic yards at $16.00	=	1,760.00
Mass of bases........22	cubic yards at $35.00	=	770.00
	Total.....	=	$7,272.00

From these figures it is evident that the hypothetical "Chromol" steel at the hypothetical pound price used would be much more economical than wire for suspension bridges of all possible span lengths.

RÉSUMÉ OF FINDINGS

Summarizing the results of the entire investigation, on the basis of present unit prices, the following conclusions are reached:

1. Neither untreated Mayarí-steel eye-bars nor heat-treated, carbon-steel eye-bars can compete with wire in the building of highway suspension bridges.

2. If Mayari-steel eye-bars, after being heat-treated, are reliable and satisfactory, it is not unlikely that they can compete with wire cables for spans up to 2000 feet.

3. Untreated eye-bars of high-grade, nickel steel are more economical than wire for spans up to 1400 feet.

4. Heat-treated eye-bars of high-grade nickel steel are probably economic for all spans less than 3000 feet.

5. If satisfactory eye-bars can be made of heat-treated "Chromol" steel, and having an elastic limit exceeding 100,000 pounds per square inch and an ultimate strength of not less than 150,000 pounds per square inch, they will be more economical than wire cables for suspension bridges of any feasible span lengths.

DISCUSSION

Dr. J. A. L. Waddell: Gentlemen, I can tell you a great deal about the economics of bridgework now. Practically all these things I have worked out are new; hence it might interest you to hear what these economic investigations of mine have been.

After I finished writing "Bridge Engineering" some four years ago, I recognized that there was one subject which was not complete, and that was the economics of bridgework. I then listed eight major economic problems (adding two more a little later), and tried to persuade some other engineers to help on the solution of them, but I failed in that endeavor; consequently, I started out in 1916 to make the solutions myself. The first problem was the Economics of Steel-Arch Bridges. In that I recognized eight important questions to solve, and I solved them. Then I gave the results in a paper to the American Society of Civil Engineers, and it was discussed and a summary written, after which it was published.

Next was the Economics of Cantilever and Suspension Bridges. My reason for investigating that subject was that it had been treated only once, and then by a very young man without experience, who had made a great many mistakes. His conclusions were all wrong, and I did not want to leave the profession with erroneous data. I made an elaborate series of calculations myself without any assistance and checked their correctness by plotted curves—so I know I was not wrong—and I found results entirely different from those which the young man found.

My next problem was the Economic Span Lengths for Simple-Truss Bridges on all Types of Foundations—and for depths as great as 250 feet. You may think that a very great depth and that I was crazy for figuring bridges for such an extreme condition. If so, I must tell you that, if we build a bridge which I have been working on at New Orleans, we shall have to go down 250 feet below Gulf level with our piers.

Next came an investigation on Possibilities and Economics of the Transbordeur, as it is called in France where it was origi-

nated, the transporter bridge in England, and the aerial ferry in America, where there is only one example of the type, viz. a structure at Duluth, Minn. Let me tell you what I did for that type of construction. It was in connection with my studies as a member of the Board of Advisory Engineers to the Public Belt Railway Commission of New Orleans on the projected bridge or tunnel for crossing the Mississippi River near that city. I have permission from the Bridge and Tunnels Committee to publish this, although the report has not yet been made public. The transbordeur, as it is built to-day, is a single-span, single-track, single-carriage, slow-motion structure. In Europe there are some forty of that type. I have developed a multiple-span, multiple-track, multiple-carriage, rapid-transit structure; and as I have designed it, it has a carrying capacity approaching that of a real bridge. As far as pedestrian traffic goes, it beats the bridge, because pedestrians go over the latter at about three miles per hour, while they can be taken across by transbordeur on the upper deck at the rate of fifteen or twenty miles an hour; hence the transbordeur can carry more pedestrians than can walk over in a given time. As for its capacity for street cars, it will probably carry enough of them; but, if it were in competition with a bridge, the bridge would beat it. Street-cars can be run at fair speed quite close together on a bridge. But when it comes to the automobile the bridge has the transbordeur beaten badly.

That was Paper number 4. Numbers 5 and 6 I have given you to-night. Number 7 was the Economics and Costs per Foot for Reinforced-Concrete, Steam-Railway Trestles. I have solved all the economics of that problem for the slab type and for the girder type of structure. There are not many variables, for the economics will vary only with the live load, the span length, and the height.

There is one more question that I am working on now; that is, the Economics of Movable Spans; and I can tell you a little that I have learned on that subject in the last few years, but cannot give you the final word about the matter. One statement which I shall make, some of you will undoubtedly challenge; that is, that the swing-bridge is, or should be, to-day a thing of the past. It has no *raison d'être*. It is more expensive than the

vertical lift or the bascule, and it occupies right of way that does not belong to the railroad or to the parties who build it, because it turns off at right angles. Again, it is not as rigid and it does not operate as quickly. Some of you may question the latter statement, but I have a vertical lift bridge at Portland, Ore., on which the average time of blocking the highway traffic is 1¾ minutes, and there is a very nicely operated swing bridge about two miles away that takes five minutes as a minimum.

There remains the question as to which is more economical, the bascule or the vertical lift, and that will depend a great deal upon circumstances. For the crossing of rivers in the interior of the country, where only river steamers go, the vertical lift will beat the bascule and the swing-bridge every time, because the clear headway is small. Near the mouths of rivers where ocean-going steamers pass, and where the opening is narrow, the bascule is liable to beat the vertical lift. But there should not be allowed a very small opening for ocean-going vessels to pass through; consequently, I think the vertical lift will nearly always be preferable to the bascule. In a few months, however, I hope to solve that problem.

Mr. A. Stucki:* When you speak of economics, you apparently mean first cost, not considering the life of the structure. This, again, is depending on the material used, its strength, its corrosion, its workmanship, etc. Some designs, for instance, are more sensitive as to workmanship than others. Plate-girders, for instance, are more immune to this factor than trusses. Have you given consideration to these various items entering into the life, thus determining the economics in the long run?

Dr. J. A. L. Waddell: In these two papers I did not; it was first cost. But the question of deterioration has been treated at length in the book which I am writing on the "Economics of Bridgework." But let me tell you that, as far as steel bridges are concerned, this matter of deterioration is not as important as you might think; because, as I maintain, a modern steel bridge, properly designed, properly manufactured, properly

*Consulting Engineer, Pittsburgh.

erected, properly painted, and properly taken care of, will last for an indefinitely long time. It requires good care to keep it painted. I have lately been in the South examining some bridges that have been up a good many years; and I found in the floor system, in places, very great deterioration; but, in the trusses, hardly any. I scraped off the paint and discovered the original shop coat of red lead on some of them that were erected in the early days.

Mr. A. Stucki: I would like to know whether you find any undue deterioration in the machinery used in raising the bridge in Portland, Ore. I saw it in operation but did not make special inquiries.

Dr. J. A. L. Waddell: I have not heard of any deterioration in the machinery. All machinery will wear out in time and will have to be taken care of; but, as for comparison of swing-, bascule-, and vertical-lift bridges, there is not much to choose between machinery for the three in respect to deterioration.

Mr. E. W. Pittman:* When is this book to be published?

Dr. J. A. L. Waddell: I hope to publish it this year. I have written 36 chapters out of 43. As soon as I can finish the last investigation on the economics of movable spans, I can complete the book pretty quickly. It takes several months to get it out after the manuscript is prepared for the printer, but that is now quite well advanced.

Prof. Horace R. Thayer:† I would like to hear a brief summary of the results for the steel arches, if the speaker will give it.

Dr. J. A. L. Waddell: First of all, I will take the general problem. Is an arch more or less expensive than a simple truss

*General Manager, Dravo Contracting Co., Pittsburgh.

†Associate Professor of Structural Design, Carnegie Institute of Technology, Pittsburgh.

bridge? That will depend somewhat on conditions. You have to take into account the substructure as well as the superstructure. My general investigation showed that there was a gain in material, and the longer the span the greater the gain, and there was more gain for the arch in a highway bridge than in a railway bridge. The result will be, I think, that we shall build more arch bridges in the future than we have built in the past. In a great many cases where we adopt truss bridges we could put in the arch to advantage and have a much handsomer structure. I hope that after my investigations are studied and reproduced in this book, where they will be available, we shall be building a good many more arch bridges than we are building to-day.

One of the remaining problems was the economic ratio of rise to span length. It averaged about 22.5 per cent. for a three-hinged arch; but it does not make much difference if you pass as low as 20 per cent. or as high as 25 per cent. In all my economic investigations I have noticed that when I have found the economic limit, I can pass quite a distance on each side of it in the curve without making any material difference in the cost; but pretty soon the curve commences to go up so that when you pass very much beyond the economic limit in either direction you increase the cost quickly and materially.

Another of the problems was the economic ratio of depth of arch ring to span length. At first I found that function by means of a mathematical theory based upon a formula which I had worked out for weights of metal in arch ribs. I thus determined that ratio to be 7.5 per cent; but it was afterwards changed. Mr. Fowler showed in his discussion* that it did not agree with the average of actual practice in cases of 100 arches for which he collected data; consequently, I promised to compute it in a manner that would leave no doubt whatsoever. I took a 500-foot span and worked out the actual weights of metal for different depths of arch ring, and I found that I was about right for spans of 100 feet, only. Instead of 7.5 per cent. it was 7.8 per cent. for a 100-foot railroad bridge, but the longer the span the smaller

*Proc. A. S. C. E. Aug. 1918.

it got. It went as low as 5.4 per cent. for a 1000-foot span railway-bridge; and for a highway bridge of that span length it was even less.

Another economic problem was "which is the most economic; the three-hinged arch, the two-hinged arch, the one-hinged arch, or the arch without hinges?" I found that the two-hinged arch has a little advantage over the three-hinged one, but not very much; that the hingeless arch is more expensive than the others, and heavier; and that the best type is a three-hinged arch for the dead load, converted after erection, and after it gets its dead load, into a two-hinged arch for the live load. There is not very much difference in the cost; but it is a better bridge.

Then I investigated, also, in a three-hinged arch where one should put the hinge—in the top chord, the bottom chord, or the middle. Theoretically, it seemed that it should be in the bottom chord; but, actually, the calculations showed that it is in the top chord. That was for the spandrel-braced arch; but with arch ribs I would put it in the middle in any case, without figuring it economically, because that is the proper and logical place for it.

Another investigation was the economics of the cantilever arch, which is an ordinary arch span with flanking spans, each consisting of a cantilever arm supporting one end of a simple-truss span, the other resting on a pier. I found there was a saving of about 12 per cent. in the metal of the entire structure by adopting the cantilever principle. That was the maximum I could find, and the ratios of cantilever arm and suspended span to the total length of flanking span were, respectively, 40 per cent. and 60 per cent.

Those were the main economic problems I solved in relation to steel-arch bridges.

Prof. Horace R. Thayer: In figuring for the two-hinged and the three-hinged arch did you allow any higher stresses for temperature?

Dr. J. A. L. Waddell: Yes, when everything was included, I allowed a higher intensity, which, I think, eliminated the consideration of temperature stresses; just the same way as in ordinary truss-bridges we allow for combined wind stresses and other

stresses 1.3 times the ordinary intensity, and that generally takes care of the wind stresses in all ordinary bridges. In light bridges it might not, but in heavy bridges, it would. So I think that, as before stated, in that particular case the temperature stresses were canceled by allowing a higher intensity for the combination.

COL. E. K. HILES:* This question may be a little outside the discussion, but I would like to know, as to the matter of cable suspension bridges, just how the determination is made as to when the practical life of the cable has been reached and when it is time to tear down the suspension bridge. I wonder if they ever attempt to determine the extent of the corrosion of the broken wires by electric conductivity, or whether the determination is made by a superficial examination only.

DR. J. A. L. WADDELL: As far as I know, it is by superficial examination; but I have never made such examination myself.

COL. E. K. HILES: Some of the earlier ones have been torn down within the past few years.

DR. J. A. L. WADDELL: Yes, but the cables were not properly taken care of in old times. They ought to be painted with a special preparation every two or three years, especially, near where the cable enters the concrete. At that place there is likely to be deterioration.

COL. E. K. HILES: A number of small lines of cable, possibly two feet long, with the ends thoroughly protected, might be suspended in the bridge; and at intervals of a number of years, when the condition of the main cable would indicate the necessity, one of these dummy cables might be taken down and torn to pieces to see just what the situation was. If they had enough of them, it might be a good solution.

DR. J. A. L. WADDELL: That would be a good scheme. I never heard it suggested before.

A. C. STALKNECHT:† The protection of the cables of the Brooklyn Bridge might in a degree answer Col. Hiles. I have had occasion to examine the exterior of these cables a number of times

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†Proprietor, U. S. A. Grease Co., Pittsburgh.

and have noticed their diminution in diameter from 15.5 inches to under 14 inches in several places. The four cables were built up over solid cores with 6300 seven-gage wires. The great mind which conceived this construction—the elder Roebling—appreciated the importance of both protection and lubrication even for this stable construction. A comparatively small lateral and vertical oscillation accounts for the reduction in cross section of these cables and for the shear and elongation. Vaseline, being both lubricant and protective against moisture and the gases endured, partially met the requirements but failed in melting point. Its application was continued for some years after the opening of the bridge in 1883. Rope makers are somewhat chary about advising as to proper methods of protection against corrosion and for lubrication, but the experience on this great construction would suggest that the treatment should be both protective and lubricant and that the material should be adhesive, moisture proof, gas proof, non-oxidizable, non-hydrolytic, non-catalytic, and should be free from tar, asphaltum, pitch, and linseed oil; since they oxidize, dry out, lose their elasticity, fracture, and admit moisture and gases. The material should be semi-solid within the range of the temperature of service. It should be a stable, neutral blend or compound which cannot be altered physically nor be rendered acid by the mediums from which the ropes must be defended. A wire cable is a very mobile structure and the maker should supply a very high class lubricant to the core before spinning the strands about it.

The problem seems to be as much one of interior lubrication as of exterior protection against corrosives. Alkaline treated Texas and Mexican road tars are much used for this purpose and fail because of the lack of a proper conception of cable structure and its needs.

For other than the suspension type, for the solid construction—in fact for all static iron and steel construction—even the exhaustive tests of Sub-Committee III of Committee A-5 of the American Society for Testing Materials do not seem to give much encouragement. Some members of this Sub-Committee are not inclined to recommend any particular protective treatment. It still seems an open question. Some years ago I was greatly in-

terested in the protection afforded the six Soo bridges. A neutralized and further treated gas-tar protective had been provided. It was thoroughly effective above the "dog-line"—a line 2½ feet above the bridge floors. The designation of this line I did not understand. Within this zone, on removal of two rusts—one darker than the other—one showed the composition $Fe_2O_3 + 2H_2O$., the other $Fe_3O_4 + H_2O$. The corrosion did not occur in even planes but the surfaces were impregnated with pits of varying depth and diameter, some as much as 3/32 of an inch deep. Above this zone no rust had formed for four years and the protective was elastic and intact, while nothing up to this time had been found adequately protecting below this 2½-foot level. The engineers and the city fathers seemed to agree that the subject was one worthy of the intense research of both the industrial and pathological chemist and that the limits of the "dog-line" were purely a function of sex.

Mr. Willis Whited:* As far as the resistance of the wire cable to corrosion is concerned, I feel that engineers can pretty fully set their minds at rest on that, because it is a well known fact that iron rust occupies about four times the space of the metal it is made up of, and, before there is a deterioration of more than one or two per cent., there would be a swelling in the cable plainly manifest which would set some one investigating. I have seen a great many wire cable bridges, notably one very badly built, that have been in place forty or fifty years across the Delaware River that do not show corrosion. As I said before, the evidence of deterioration will show long before it becomes dangerous. I had some experience with the Point Bridge, here. It had been up about 25 years when we overhauled it pretty extensively. To make sure of the condition in which the cables were (they were eye-bar cables), we tore down the masonry quite a distance—on one end, 30 or 40 feet—partly for reconstruction purposes and partly for examination. The masonry was built in the old fashioned way; the outside was well laid ashlar and the backing was built up loose in layers of about four inches and grouted and the grout worked in about six inches, and

*Engineer of Bridges, State Highway Department, Harrisburg, Pa.

the rest was loose stone. After we got down two or three feet into the wall there was hardly any appreciable corrosion—just a thin skin of rust, and the paint was hardly damaged.

You speak of the economics of long-span bridges, and the fact that you ignore wind stresses in the chords.

Dr. J. A. L. Waddell: That depends a great deal on the width of the bridge. You would not use long-span structures except for city bridges that have to be pretty wide.

Mr. Willis Whited: You speak of the proposed bridge across the Delaware at Philadelphia having two 22-foot roadways.

Dr. J. A. L. Waddell: That is one of the lay-outs. They have not yet made up their minds as to what they want.

Mr. Willis Whited: My idea would be that for two lines of traffic, 18 feet, or perhaps a little more, is enough, and for three lines of traffic you ought to have at least 24 or 26 feet.

Dr. J. A. L. Waddell: The traffic is in one direction only. You need a good deal more space when traffic goes in opposite directions.

Mr. Willis Whited: Yes, of course; if you have two lines of traffic in the same direction, one will move faster than the other and they need a little more room to pass. 18 feet might be a little narrow but I do not think 22 feet necessary.

Dr. J. A. L. Waddell: I am a little ahead of the game in that. In New York they allow 20 feet. Out in Vancouver a number of years ago I built a structure with a 42-foot roadway and two sidewalks. Afterwards I had to build a similar bridge about half a mile away over the same stream, and the city council asked me to cut a foot off each sidewalk and put it on the roadway. They found out by experience that a 44-foot width was better than one of 42 feet.

Mr. Willis Whited: Were there street-cars on it?

Dr. J. A. L. Waddell: Two street-car lines, I think.

Mr. Willis Whited: On the South Tenth Street bridge, in this city, there were two street-car tracks and we found by experience in the streets of the city that a 30-foot roadway was hardly wide enough, so we made it 32 feet and I believe experience has shown that it should be a little wider. I made the new Point Bridge 36 feet. That would leave a line of traffic outside of the street-cars. Possibly 34 feet would have been enough, but with trucks eight feet wide, such as they use now, 34 feet is not sufficient.

In building long-span bridges in the city it pays to go to a good deal of expense to put in reinforced concrete floors and a good substantial pavement; but in highway bridges the economy of creosoted wood blocks is so great that we can not resist the temptation to use them for spans up to 200 feet.

Dr. J. A. L. Waddell: I have had some pretty hard luck with those creosoted floors. The Germans tried to burn two of them in one night in Vancouver. One of them was burned pretty badly, and the other was started burning five times; but the fire was put out each time before serious damage was done. I have had a great deal of trouble with fire and I have built my last floor of creosoted planks.

Mr. Willis Whited: Out in the country, in a place where it is a question of a cheap bridge or none at all, you can take some chances.

Dr. J. A. L. Waddell: There is a way to secure a lighter floor by using buckle plate. That type has failed in times past by not being stiff enough and hence cracking the pavement; but if you rivet on angle irons from stringer to stringer—say 3 by 3 or 3½ inches—and cover them, leveling off with asphalt and putting on a thin covering of bitulithic pavement, you will get something as light as you can well put in, and it will serve its purpose

without breaking up. I think we shall have to come to that for very long spans for highway bridges where they have not enough money. I have not yet built a floor of that type.

Mr. Willis Whited: We have some bridges in this city with buckle-plate floors—one across the hollow from Schenley Park. I have not heard whether the buckles have deteriorated or not. They have been up eight or ten years.

Mr. Paul L. Woelfel:* In comparing the cost of continuous-truss and single-truss spans, there is one thing that I believe has not been fully taken into account. On long-span bridges, very often on account of economy of erection or on account of requirements imposed upon us during construction, a wide channel has to be kept open. For the Sciotoville Bridge for the Chesapeake and Ohio Northern Railroad this channel opening was over four hundred feet. On account of this, there will often be a material saving if continuous trusses are used.

Dr. J. A. L. Waddell: You can use the semi-cantilever method, or you can block one channel, put up one span, take down the false work and erect it on the other side, and then put up the other span.

Mr. Paul L. Woelfel: No, you have to keep open the span on the other side.

Dr. J. A. L. Waddell: You can work out a scheme. It adds a little to the cost, of course.

Mr. J. S. Martin:† The papers presented by Dr. Waddell this evening are along a line in which enginering literature is sadly deficient. It is not at all surprising that Dr. Waddell's efforts met with such indifference on the part of those who are considered leaders in the profession. The structural engineer has so long been the victim of the "hurry-up-and-shove-it-through"

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†Structural Steel and Concrete Designer, Duquesne Light Co., Pittsburgh.

idea, that time spent in scientific study of the economics of the design or construction is considered wasted. I have seen months of time and thousands of dollars wasted on a single job, where three weeks of careful study and investigation would have saved much of this time and money.

Another point, which is detrimental to economy, is the lack of co-operation between engineers in different lines. As an example of this, let us suppose that a company desires to build a boiler-house. A common method of procedure is to send out for competitive bids from the different bridge companies, for the building, each company submitting its own design. Bids are also asked from the different boiler companies; each, as before, submitting its own design. The same is done with the stokers, and, as an after-thought, usually, with the coal handling and storage. There is no thought given to any co-ordination of these designs, except just sufficient to have the job go together. The result is a "crazy-quilt" affair, which is a prolific source of profanity to all who have to operate the plant. The cost of such an agglomeration is invariably greater than it would have been for a correctly designed plant.

I am glad Dr. Waddell is going to take up the matter of designing with a view to preservation. Entirely too many engineers absolutely neglect this very important point.

I have only once tried designing continuous trusses with a view to reducing the weight of steel. The spans were not over 150 feet long and I found, as Dr. Waddell did, that on short spans, continuous spans show little, if any, advantage in weight over simple spans. I was surprised at this at the time, but have checked the results since and find this to be the case.

Dr. J. A. L. Waddell: I did not know that fact until I made these calculations.

Mr. C. B. Pyle:* Why is it necessary to shrink the eyebars on the pins?

Dr. J. A. L. Waddell: You would have an awful time away up in the air hammering at them. I will tell you a scheme

*Engineer, McClintic-Marshall Co., Pittsburgh.

which I have lately evolved. I would make those eye-bars with half the eye enlarged in the front, and would use what might be termed a hot box case containing either electric wires or tubes for hot air; and I would thus lengthen the bar so that the wide part of the hole would slip over the pin easily and when I took off the heat it would shrink and come to a bearing, leaving in front a little open space between the pin and the head which would have to be filled very carefully with some paint that would stay there. It would take forever and a day to drive those bars home without some such contrivance.

I might say that I have found some exceedingly interesting results in my studies of the economics of alloy steels and the comparative economics of bridges and tunnels—the two additional major economic problems previously mentioned. I have solved the problem for the crossing of the North River; and I shall tell you what I have found. I surmised that the best and most economical solution is to carry the street-cars and the electric trains of the subways beneath the river and to carry the automobiles above. To show whether I was right or wrong in my surmise, I made two sets of estimates, one for a highway bridge, pure and simple, to carry electric cars but not trains; and the other for an electric-railway structure with open floor. I made estimates of cost for three openings, under the assumption that for the North River we could put in a span of 1500 feet; one of 2300 feet; or one of 3000 feet. I wanted to get a curve to represent the total cost of bridge and approaches, without the right of way. I plotted the total costs for those three openings, and then I took the costs of the tunnels for the different assumed openings from the investigations that have been made lately by the engineers of the New York State Bridge and Tunnel Commission, and then plotted the corresponding curve on the same sheet, finding, as I anticipated, that, even for the 3000-foot span, the highway bridge has the tunnel very badly beaten—so much so that the difference in cost of right of way could not possibly compensate for the saving; nor could the fact that you can build the tunnels a tube at a time. On the other hand, I took the case of a wide bridge for electric subway trains of ten cars, and plotted the cost of that bridge and approaches for those three spans, and then ob-

tained the cost for the corresponding eight single-track tunnels, without the right of way, and found a saving of $5,000,000 for a 2900-foot span in favor of the tunnels, in addition to the difference in the cost of right of way. Again, there is the fact that you have to build your bridge all at once, while you can build one or two or three pairs of tubes as you need them, thus involving a large saving of interest. This investigation entirely justified my anticipation that the proper solution of the problem of crossing the North River with subway trains is by tunnel and not by bridge.

If you were the engineer of the electric railroad company you would find it much more economical, when you are paying your bills for power, to dip down about 100 feet in order to go under the river rather than to climb 200 feet in the air. Of course, the same reasoning would apply to the automobile, but who thinks of that when he is driving one?

Another matter of even greater importance is this. I do not believe it will ever be safe to go through long tunnels with automobiles on account of the poisonous carbon monoxid gas given off as a product of combustion. They say they can take it out, but it will cost a lot of money to ventilate a tunnel for automobile traffic. Then, too, CO is a cumulative poison, like arsenic; and its continued inhalation eventually will ruin one's health. Suppose there is a breakdown and a lot of automobiles are in the tube giving off this poisonous gas—you may have a disaster. As the bridge is more economical in first cost than the tunnel, for highways, and more economical also in respect to maintenance and repairs, why not use the bridge for the automobiles and the tunnel for the electric cars? When I say the cost of maintenance is greater for highway tunnels I include ventilation, which is very expensive.

In regard to alloy steels, I found very interesting results in that economic investigation; and after finishing it I wrote a paper on the subject, employing French units, and sent it to the Académie des Sciences, in France, but I have not yet heard whether it has been accepted.

From the diagrams prepared, one can settle the question as to which is the more economical of any two steels for any pro-

posed bridge, provided you know the costs per pound of the two metals in place and the elastic limits or the intensities of working stresses which you can use.

Mr. J. G. Chalfant:* My experience has led me to believe that 20 or 22 feet is the minimum width for a two-track bridge for highway traffic; 30 feet for three-track travel, and 38 feet for four-track travel.

Where I believed the demands of travel require more than two tracks, I would build four, using three only when required to meet structural demands, as on long spans where the minimum between trusses is about 32 feet.

Mr. Willis Whited: Regarding the four-track bridge, I think it is hardly safe to make it as narrow as 36 or even 38 feet, unless there is a guide of some sort in the middle to separate the two lines of traffic. The two inside lines must have a guide or they will get too close to each other.

Dr. J. A. L. Waddell: That is the reason I preferred 42 feet. In these days, when we have prohibition, perhaps it is not so important.

Mr. A. Stucki: As to the nickel steel mentioned, I again wish to point out the great difference in qualities affecting the life. Compared, for instance, with vanadium steel, the two have practically equal strength under static loads, but under dynamic shocks crystallization takes place much sooner in one case than in the other and my experience with axles and springs has disclosed most astounding differences. Have you gone far enough in your work to make proper deductions in the first cost to compensate for such differences?

Dr. J. A. L. Waddell: In bridgework we do not have any shock worth mentioning, compared with what you have in mind—that endured by automobile steels. The shock in automobiles is something immense. There is no telling what the resulting

*County Engineer of Allegheny County, Pittsburgh.

stresses amount to, but the dynamic effect of blows in bridges, especially long spans, is very small. The longer the span, the less the dynamic effect. And for a highway bridge or an electric-railway bridge, you may disregard it altogether in a long span. Steel bridges never wear out from fatigue. We do not stress the metal high enough for that. The old bridges failed mainly from lack of brains on the part of the designer of the details; for they failed in detail. They were very light and vibratory, and the stresses set up by vibration affected the details even more than they did the main members. Again, those structures were not taken care of, hence they rusted, and that often was the main reason for failure.

Mr. A. Stucki: I know I speak for myself and I believe I speak for the members of the Society and all those present when I say that I am very glad to have been here, and I will go out knowing much more than when I came in. It has certainly been a great treat to listen to this paper and the remarks of Dr. Waddell, and it is an honor to the Society as well as a matter of mutual advantage and pleasure. I would like to move a vote of thanks to the speaker for his excellent paper and discussion.

STEAM POWER-PLANTS AS APPLIED TO VEHICLES FOR COMMON ROADS

By F. L. Egan*

The purpose of this paper is to present, in convenient form, an outline or brief history of steam power as applied to common road vehicles. The subject is a live one, because the entire civilized world, of necessity, must have in the future even more than to-day, safe, rapid and economical transportation. It was something of a shock to realize—as we have recently—the dire results of a failure in rail transportation.

Transportation from gasoline fuel is high-cost transportation because gasoline is a high-cost fuel for the available power or B.t.u. it contains. See Fig. 1–3.

Fig. 1. Sidney, Straker and Squire. Seven-Ton Steam Truck to Haul Trailer.

*Engineer on River Equipment, Carnegie Steel Co., Pittsburgh.

Fig. 2. Sidney, Straker and Squire. Five-Ton Steam Express Wagon.

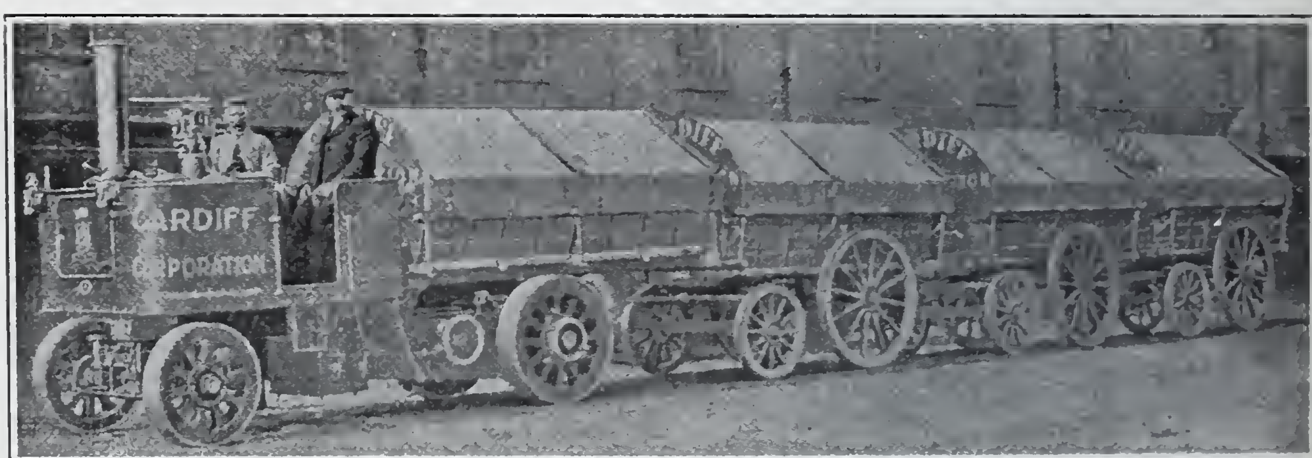


Fig. 3. Mann's Steam Wagon Company, Leeds, England.
Steam Wagon and Trailers.

England seems to have produced the first commercially successful steam wagons and they were a development of early plowing engines such as those produced by Aveling and Porter. Their early success, which has continued to the present time was no doubt due to sound engineering, sturdy design, good workmanship and materials; and also to the fact that the manufacturers did not expect the purchaser to buy their experiments. Prominent English builders to-day are: Clayton and Shuttleworth, Ltd., Foden, Ltd., Garrett, Ltd., Taskers, Ltd., Wallis and Stevens, Ltd., and the Yorkshire Steam Wagon Company, Ltd.

During the summer of 1913 the Terminal Transport Company, of New York, imported two Foden six- to seven-ton steam wagons made by Fodens, Ltd., of Sandbach, London. See Fig. 4.

Fig. 4. Foden's Steam Wagon and Trailers.

The wagons are operated by a driver at $33 a week and a helper at $15. They carry six tons in a dumping body and haul a trailer over very rough roads in contracting work. The trailer load is three tons, and the average daily distance is 42 miles. Hard coal of the highest grade is used by these vehicles although soft coal of the cheapest grade is in use in England. The daily cost for coal is $1.50, or 3.58 cents per mile. Oil of the cheapest grade is used, that used to lubricate these wagons costing but 40 cents a gallon. The ton-mile cost, figured on the basis of the present daily average of 40 miles and the total cost per day of $18, is 10.5 cents. The load carrying platform is nine feet long and six feet wide and the sides are three feet deep. See Fig. 5–6.

The boiler is designed and built along the lines of a horizontal locomotive boiler and is hydraulically tested to 350 pounds, for a safe working pressure of 200 pounds. The fire-box is made large for the use of coal, coke, or wood fuel. The total heating surface in the fire-box and tubes is 70 square feet.

The engine is of the compound type. The steam-jacketed cylinders are four inches (high pressure) and 6.75 inches (low pressure) with seven-inch stroke. The engine is fitted with the Foden high-pressure gear, whereby it can be converted instantly into a double high pressure, each cylinder receiving steam separately from the boiler and exhausting independently into the funnel. This increases the power for ascending steep grades and

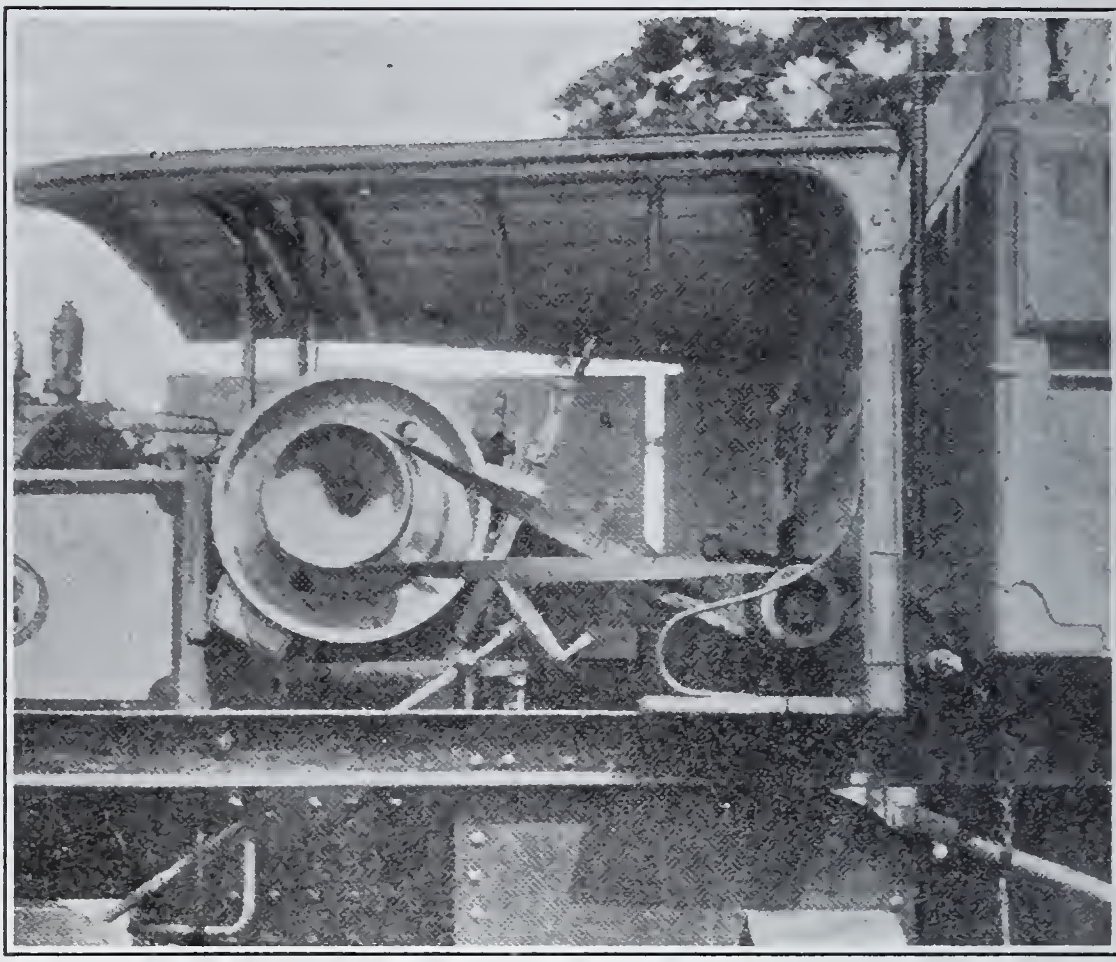


Fig. 5. View of Driver's Seat.

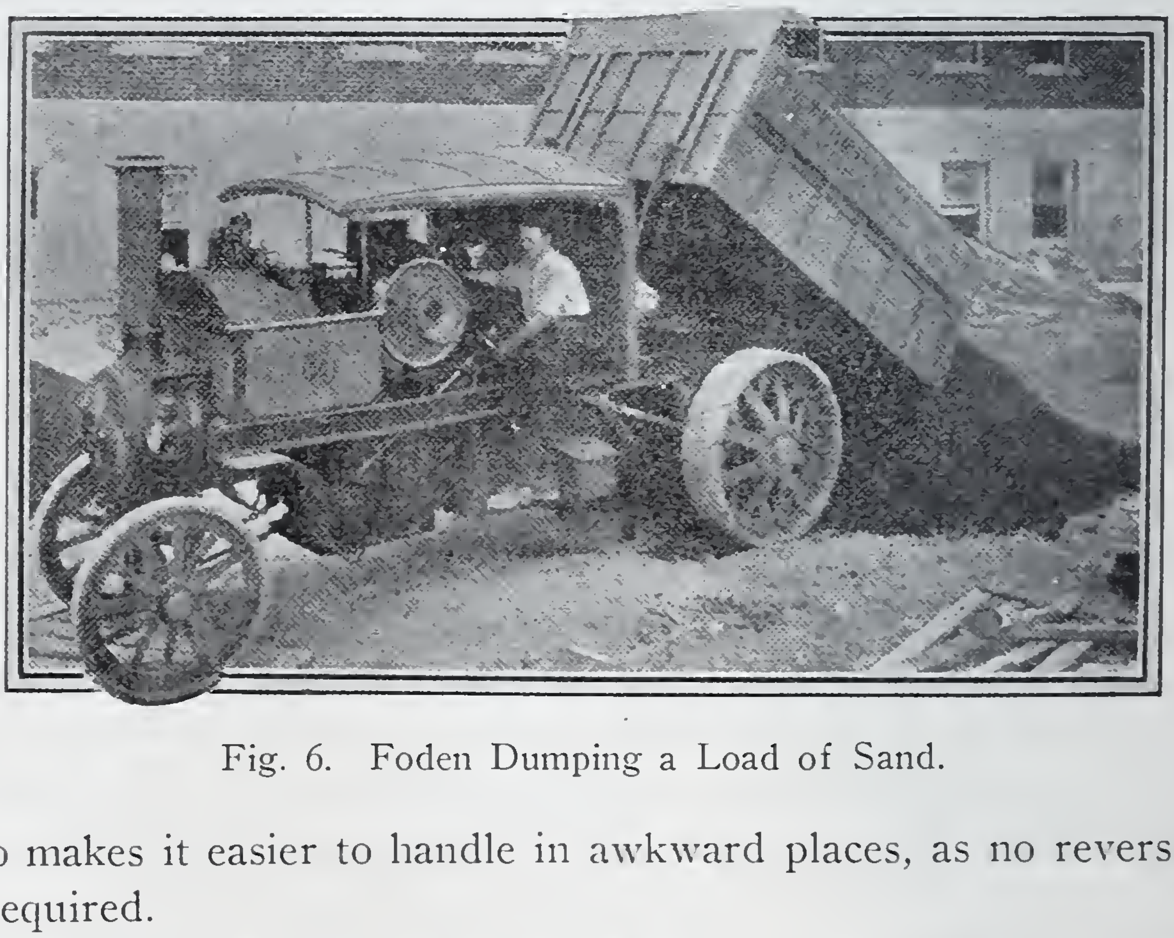


Fig. 6. Foden Dumping a Load of Sand.

also makes it easier to handle in awkward places, as no reversing is required.

Sufficient water to carry the vehicle 18 to 20 miles is carried

in the water tank, which has a capacity of 150 gallons. The fuel bunker will hold sufficient fuel for a 40-mile run. The water lifter for pumping the water from streams, wells, or horse troughs is fitted with 24 feet of 1.5-inch suction hose. One pump and one injector are fitted for feeding the water into the boiler. A two-speed gear set is provided, giving a speed of three miles per hour and one of six miles per hour. These gears are changeable by a lever. Driving is done by gears from the crank-shaft to gears on a fixed stud-shaft and from there, by a 2.5-inch pitch roller chain, to the rear axle. A large band brake operates on the rear axle and another on the fly-wheel. The driving wheels are four feet in diameter with 12-inch face. The front wheels are two feet, nine inches in diameter and have a six-inch face. They are fitted with diagonal block steel tires.

In the year 1900, Paul H. White designed and built the first steam wagon produced in the United States. He had just returned from an extended visit to England and France and was guided and inspired by the success of steam trucks in those countries.

After almost two years of work and the expenditure of several thousand dollars, a truck was produced which proved surprisingly successful from a practical standpoint.

The second machine built was of 14,000 pounds capacity, and 50 rated horse-power, with steel wheels cast in one piece. It was beautifully designed, with three-point suspension of the chassis frame on wheels, and several features that even now are being exploited as new.

This truck was operated in Indianapolis, Cincinnati, Chicago and St. Louis. As a test, it hauled a 10,000 pound load straight up the steepest part of the St. Louis levee, stopping and starting easily at different points in the climb. To the best of the writer's knowledge this test has never been equaled by any American gas truck.

The main frame was of eight-inch standard channels, riveted with 0.75-inch hot rivets, clip angle connection and 0.375-inch gusset-plates.

The front truck was a rectangular frame, pivoted at front and rear to the main frame. It had semi-elliptic springs, and

standard auto steering knuckles, and axle. The boiler was hung from the main frame directly over the front axle and centrally in the pivoted frame of the front truck.

The driver sat at the left, beside the boiler, with the fire-door at his right foot, the steering-wheel standing vertically at his right hand, and the throttle at the left end of the seat.

The engine was single acting with opposed horizontal cylinders. It had two four-inch, high-pressure cylinders and two seven-inch, low-pressure cylinders opposite with a common stroke of five inches. A Hackworth valve-gear with piston valves was used. There was an additional piston valve controlled by a pedal in the cab which by-passed high-pressure steam direct into low-pressure cylinders.

The two cranks were set at 90 degrees on the shaft which was a solid nickel-steel forging 1.75 inches in diameter in the pins and main bearings. The connecting-rods were cast in one piece of very high-grade bronze with no adjustment provided for the piston pins. The engine was oiled with a small two-gear pump which delivered the oil to a spray pipe directly over the main bearings and crank pins, the oil running to the bottom of the crank case where it was again picked up by the pump and recirculated. The steam cylinders were lubricated by a mechanical force feed oiler such as are used in the best stationary practice.

The working pressure of the steam was 225 pounds per square inch, the boilers being tested to 375 pounds per square inch hydrostatic. The boiler was a water-tube very similar to a "Heine" except that no baffles were used. The boiler was 30 inches long from tube-sheet to tube-sheet, the tube-sheets being 0.625 inch thick. The boiler contained one 10-inch lap-welded pipe which formed the steam-drum—two 3.5-inch tubes, four 2.25-inch tubes, forty-eight 1.125-inch tubes and one hundred and thirty-seven 0.75-inch tubes, these tubes all being Shelby seamless steel. The boiler was stayed by six 1.25-inch diameter shouldered tension bolts, these bolts going through the 3.5- and 2.25-inch tubes with heavy hexagon nuts outside of bumped heads.

The boiler heads were bumped plates 0.625 inch thick, bolted to tube sheets covering all the tubes, with 0.75-inch diameter

turned bolts in reamed holes spaced as close as possible, and gaskets of wire-inserted asbestos cloth.

A seamless copper float in the 10-inch steam-drum, controlled the steam supply to a Marsh steam-pump for boiler feed.

The fuel used was crushed coke or anthracite nut coal. It was found that the coke was the preferable fuel.

The feed-water was taken from a cold-storage tank by suction to a steam-pump in the cab, thence through a copper-tube, feed-water heater to the bottom of the boiler header.

The boiler jacket was of sheet steel lined with asbestos board. The stack extended straight up from the center of the boiler and the draft was created with an exhaust nozzle in the stack, and also a high-pressure steam blower as in locomotive practice. The boiler contained a total heating surface of 122 square feet, a small portion of which was above the normal water-line of the boiler.

It is amusing to recall conditions at the time these trucks were in operation. The truck company's board of directors passed a resolution requiring each truck to carry a man in addition to the driver to lead frightened teams passed the truck, which was ordered to stop and provide all necessary assistance to teams encountered upon the road.

The truck company was notified by the City Council of Indianapolis that a test must be made by operating a truck with maximum load—10,000 to 14,000 pounds—over asphalt paved streets during July, and if the pavement was injured, the truck company must repair or replace it and discontinue operating on the street. On the day of the test, members of Council followed the machine in carriages alighting at times to inspect the pavement even passing their fingers over the wheel track in search of indentation.

The third machine was sold for $2750 and the shop cost to produce that machine singly was just under $1500.

The American company was forced to suspend on account of funds and because of constant and powerful opposition from city and county Governments.

English trucks of this type had been introduced into the colonies with a guaranteed life of 10 years. One of the oldest and most successful English companies sent five trucks to Patagonia —a country of very rough roads—under such a guarantee.

Steam has been the prime motive power since the advent of the locomotive. At the time the gasoline automobile was introduced steam was successfully transporting heavy loads over common roads, and doing it at less cost per ton-mile than the very latest and most efficient gasoline truck can do to-day.

London, the second largest city in the world, has always been noted for its omnibus lines and the volume of transportation carried by them. One London company has had 200 steam-driven omnibuses in service for some six years past. Two significant facts regarding this service are:

1. Although the company formerly operated gasoline (internal combustion) and kerosene burning omnibuses, it is regularly replacing all the gasoline omnibuses with steam machines.

2. In 1915, the steam-driven machines were changed from kerosene to coke fuel. The latter fuel is fed by automatic stokers driven from the engine. Coke sufficient for about fifty miles is carried.

The most popular size—five-ton capacity—compares favorably with gasoline vehicles of the same capacity.

The following is an estimate on an equipment of 10 five-ton gasoline trucks:

Fixed charges:

Interest at 6 per cent. on cost of $4000 each	$ 240.00
Depreciation at 20 per cent	800.00
Insurance at 0.5 per cent	20.00
Storage (250 square feet at 50 cents per square foot)	125.00
	$1,185.00

Considering 300 working days, this equals $3.95 per day. Adding 20 per cent. for two spare vehicles, the fixed charges per day are $4.74.

Running expenses per day (40 miles):

10 drivers at $3.34 (10 hours)	$ 33.40
1 repairman	4.00
1 helper	2.50
Gasoline, 133 gallons at 26 cents*	34.58
Lubricants at one cent per mile	4.00
Maintenance at 10 per cent. per annum	13.33
Superintendents at 10 per cent. of operators' wages	3.99
Incidentals	2.87
	$110.64
Running expenses, each, per day	$ 11.06
Fixed charges, each, per day	4.74
	$ 15.80
Cost per vehicle mile	$ 0.395
Cost per ton-mile, both ways	0.079
Cost per ton-mile, one way	0.158

The following is an estimate on equipment of 10 five-ton steam wagons:

Fixed charges:

Interest at 6 per cent. on cost of $3750 each	$225.00
Depreciation at 10 per cent	375.00
Insurance at 0.5 per cent	18.75
Storage (250 square feet at 50 cents per square foot)	125.00
	$743.75
Fixed charges per day (300 working days)	$ 2.47

Adding 20 per cent. for two spare vehicles the fixed charges per day are $2.96.

Running expenses per day (40 miles):

10 drivers at $3.34 (10 hours)	$ 33.40
1 repairman	4.00
1 helper	2.50
Fuel at $1.50 per day per wagon	15.00
Maintenance at 10 per cent. per annum	12.50
	$ 67.40

*This is based on an average of three fleets, or a total of 84 trucks operating in the city of Pittsburgh.

Running expenses, each, per day	$ 6.74
Fixed charges, each, per day	2.96
	$ 9.70
Cost per vehicle mile	$ 2.42
Cost per ton-mile, both ways	0.434
Cost per ton-mile, one way	0.968

This estimate allows the use of the same type of tires on the steam wagon and on the gasoline vehicle. This is hardly a fair estimate, since the steam wagon is usually equipped with wood tires for city use and steel for country roads—a practice which has proven successful in several countries, including the excellent roads of France before the war as well as the almost impassible roads of new countries such as some of England's colonies.

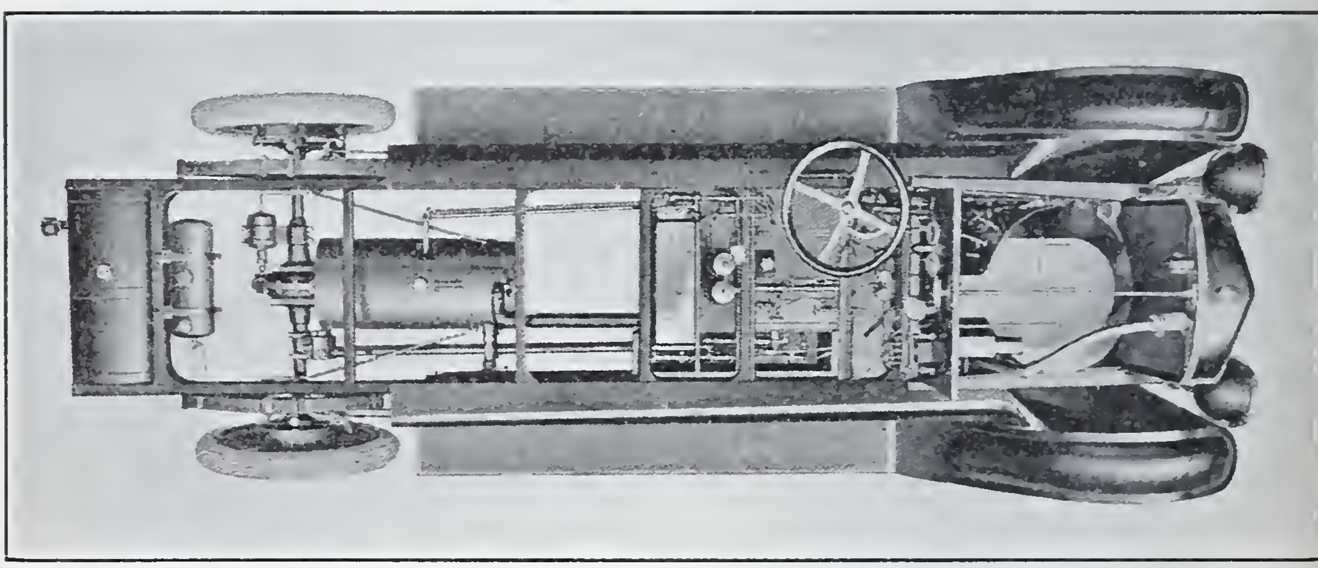


Fig. 7. Airplane View of Stanley Chassis.

The first Stanley steam car was built in 1896 by F. E. Stanley and F. O. Stanley—twin brothers located at Newton, Mass. The first Stanley cars were successful and in the fall of 1898 plans were made to build 200 cars all alike; this was the first quantity production of automobiles in the United States, and the inception of a quantity production which has been the wonder of automobile engineers all over the world. See Fig. 8.

The first Stanley car appears very odd to-day. It carried two passengers, had a small fire-tube boiler with tubes one-half inch in diameter, and was fed by a small pump driven from the vertical, twin, double-acting engine. The boiler was directly under the

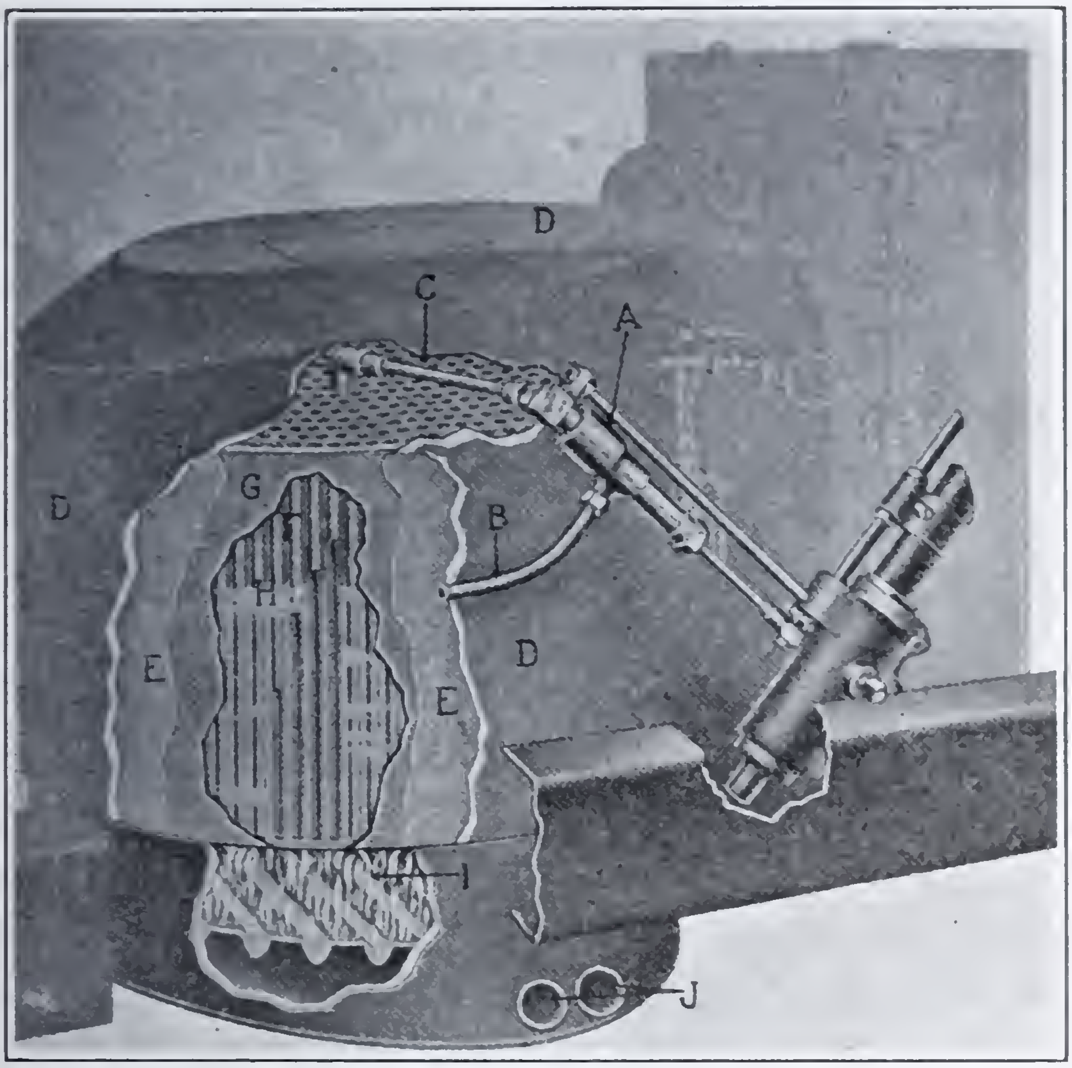


Fig. 8. Sectional View of Stanley Boiler.

seat and the engine was suspended beneath. The driver had to watch and maintain the water level in the boiler. The steam pressure was maintained automatically.

The business was sold to the Locomobile Company of America in the spring of 1901. In 1903 the Stanley Motor Carriage Company was formed and has been manufacturing cars ever since. The Stanley power-plant is made in sizes of 20 and 30 horsepower.

The boiler (Fig. 9) is of the fire-tube type, the lower head and shell being made of one piece of pressed steel, the shell being wound with steel piano wire under tension in the same way as a wire-wound gun. The tubes are one-half inch in outside diameter, expanded into the top heads by means of tapered expanders, and welded into the lower head. The upper head is welded to the shell and to the reinforcing ring. The shell is covered with asbestos insulation one-half inch thick. The 20-horse-power

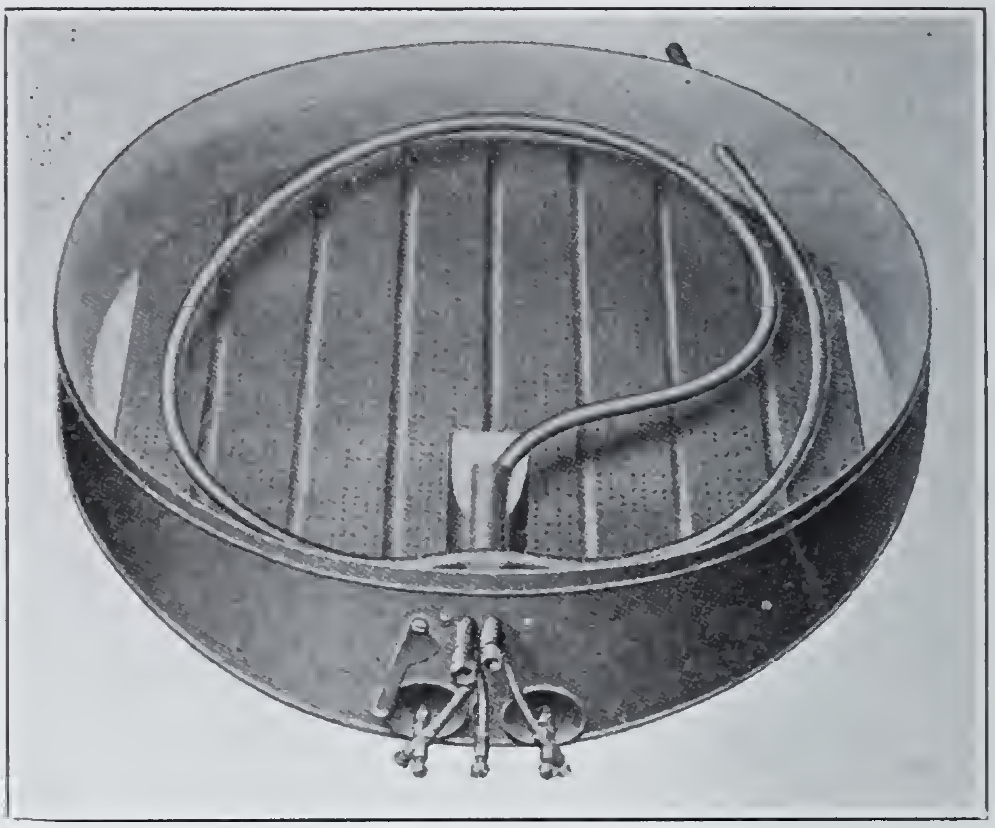


Fig. 9. Stanley Burner and Mixing Tubes.

boiler is 23 inches in diameter with 751 tubes 14 inches long, and contains 104 square feet of heating surface. The 30-horse-power boiler is 26 inches in diameter with 999 tubes 16 inches long, and contains 158 square feet of heating surface. This is equivalent to 5.2 square feet per horse-power of boiler rating. Directly over the top of the boiler is the superheater made of heavily nickeled steel seamless tubing.

The Stanley burner (Fig. 10) consists of the vaporizer, the mixing tubes and a corrugated casting with numerous small holes drilled through the flat surface on either side of each corrugation. The fuel becomes thoroughly vaporized in passing through the tubes of the vaporizer which are exposed to the flame of the burner. It issues at high velocity from the nozzles and passes into the mixing tubes, drawing with it the amount of air necessary for perfect combustion. It then enters the chamber below the casting and passes up through the drilled holes, where it burns as in a Bunsen burner, with a clear blue flame. The pilot light, burning directly under the vaporizer, keeps it hot while the main burner is not burning and will relight the main burner after it has been shut off by either the automatic or the hand valve. The burner is so constructed that it secures perfect combustion and

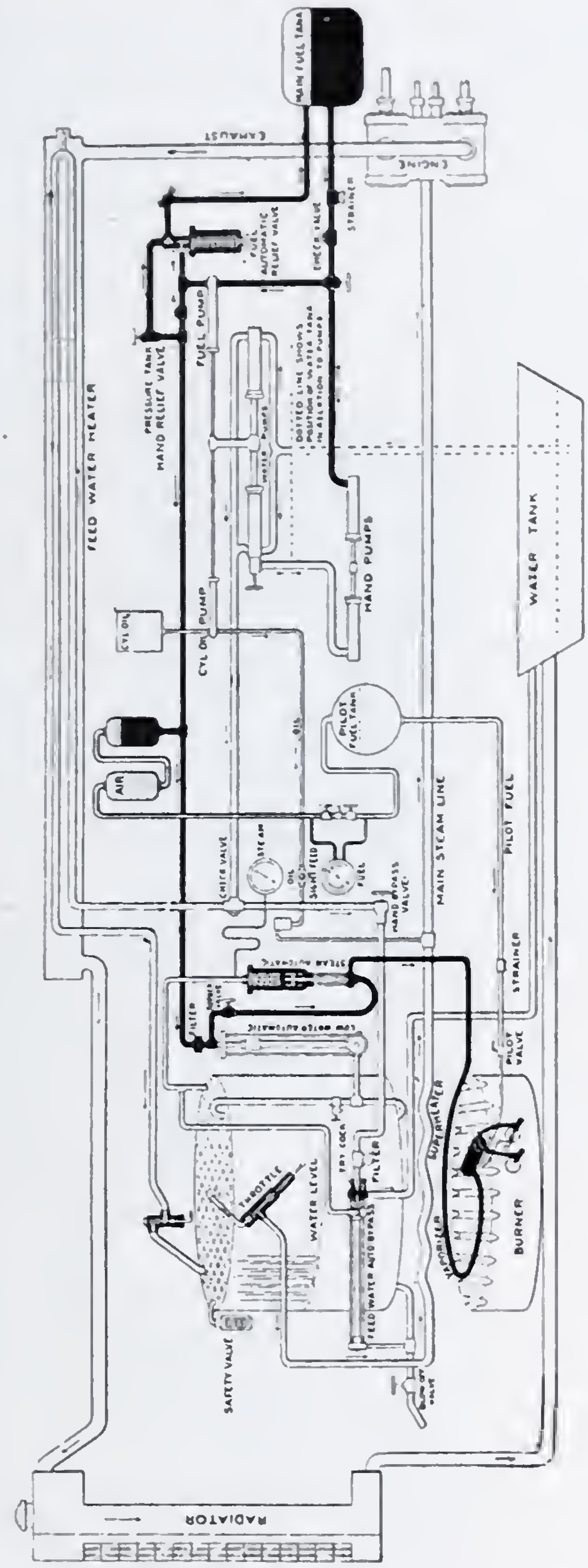


Fig. 10. Stanley Fuel System.

intense heat, and is entirely inclosed, there being no air inlet except the mixing tube; consequently it is not affected by air currents.

The burner takes equally well gasoline or kerosene or any mixture of the two in the main burner. It gives under normal conditions about 10 or 12 miles per gallon on the 20-horse-power plant. The pilot light takes gasoline and is fed from a separate

tank under about 40 pounds pressure. This tank holds about four gallons which will supply the pilot light for about one hundred consecutive hours. The tank has both a quantity and a pressure gage.

The boiler is fed by either or both of two single-acting plunger pumps driven direct from a gear on the rear axle through the medium of a single connecting rod. See Fig. 11.

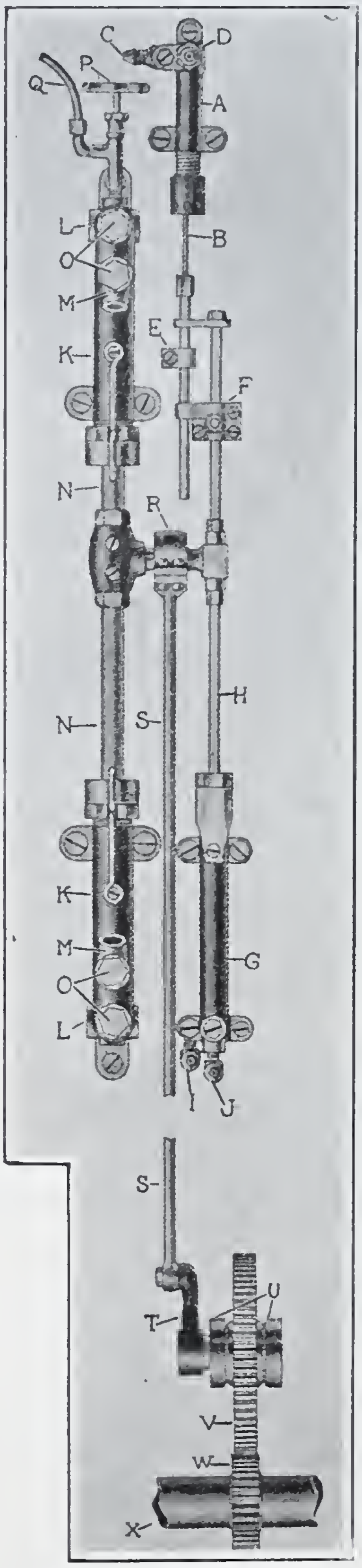


Fig. 11. Stanley Fuel, Oil, and Water Pump Assembly.

The single-acting plungers of all four pumps—that is, two feed-water pumps, one fuel pump and the cylinder-oil pump—are all connected to form a single moving part. The pumps move with the rear wheels and are governed by automatic by-passes for the water and fuel pumps. The cylinder-oil pump has a sight feed on the dash, and is regulated by a hand by-pass.

The boiler feed-water leaving the pump passes—through a feed-water heater, suspended from the sill of the car—into the boiler, with the exception that such portion of the feed-water as is not needed to maintain the water-level in the boiler, is returned to the storage tank through the automatic by-pass.

There is also a low-water automatic which shuts off the fuel from the main burner when the water in the boiler gets down to about four inches above the bottom tube-sheet.

The automatic fuel control valve (Fig. 12), or "steam automatic," controls the flow of gasoline to the main burner. It consists of (1) a diaphragm so connected that it is exposed at the bottom to the boiler pressure, and having a valve-stem in contact with its upper side; and (2) a spring in contact with the lower end of the valve-stem, which spring holds the valve-stem off its seat and in contact with the diaphragm until the boiler pressure forces the spring to yield, whereupon the valve-stem seats itself. This automatic is provided with an adjusting screw by means of which the tension on the spring can be varied, so as to make it operate at any desired boiler pressure.

The gasoline automatic relief valve (Fig. 13) allows the surplus gasoline—which is automatically pumped while running, in order to insure constant pressure on the fuel—to return to the supply tank. The valve-stem is attached to the lower side of the diaphragm, and the spring in this case holds the valve-stem on its seat until the pressure on the fuel overcomes the tension on the spring and opens the valve. This automatic is also provided with an adjusting screw.

The steam leaving the boiler passes through the superheater, then through the throttle which is controlled by a finger lever under the steering-wheel, to the engine which is a simple, twin 4 by 5

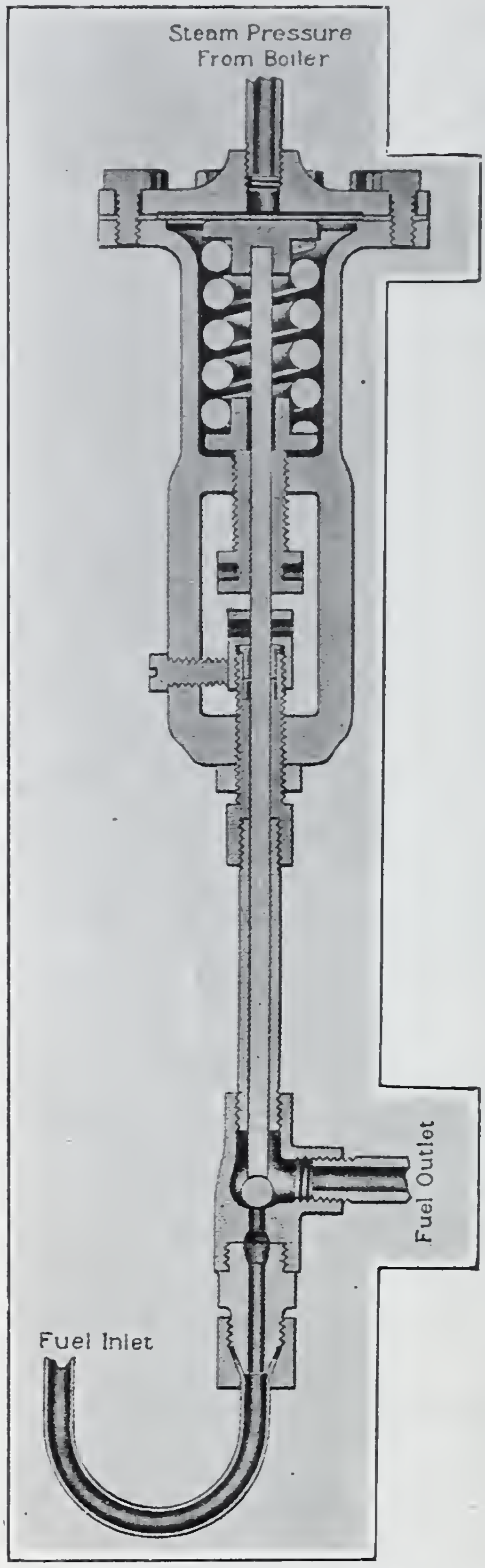


Fig. 12. Stanley Fuel or Steam Automatic.

inch for the 20-horse-power and 4.5 by 6.5 inch for the 30-horse-power.

The engine is direct geared to the differential, through a 40 to 60 spur-gear drive. With 34-inch diameter rear wheels, it makes 894 revolutions per mile for the engine, or, at 30 miles an hour car speed, a piston speed of 375 feet per minute.

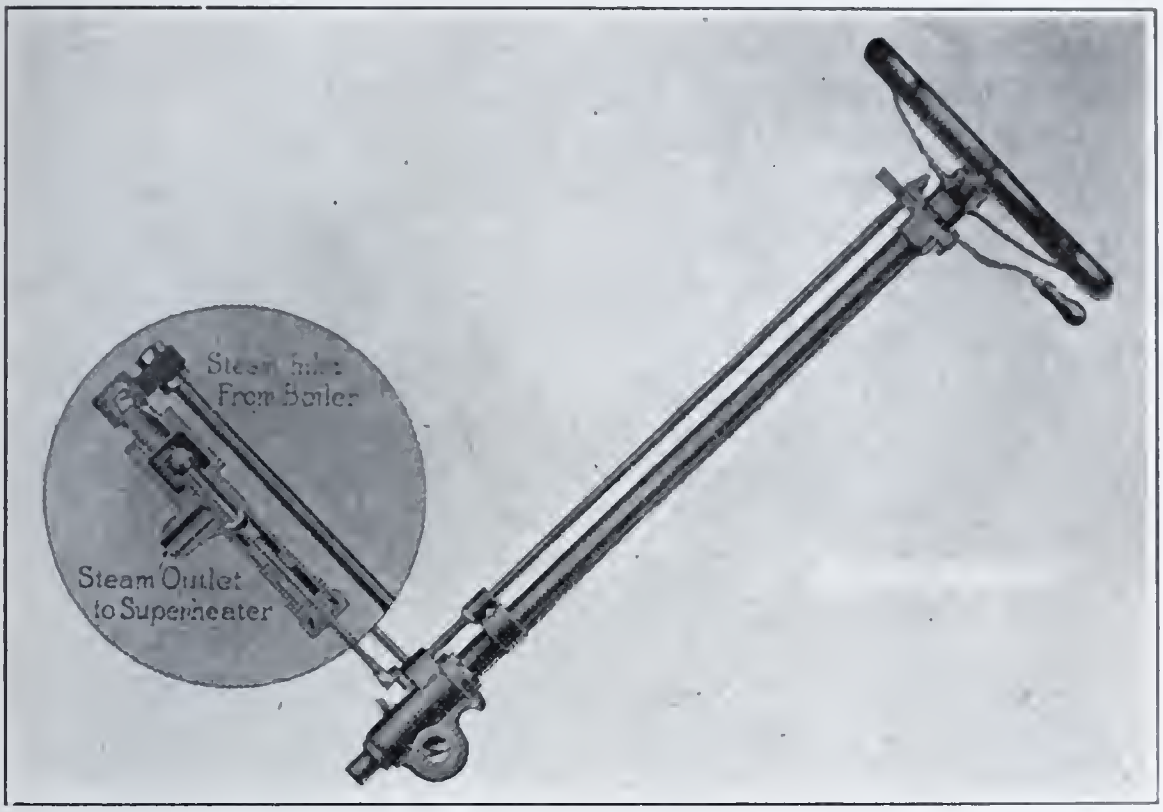


Fig. 13. Stanley Throttle-Valve Assembly.

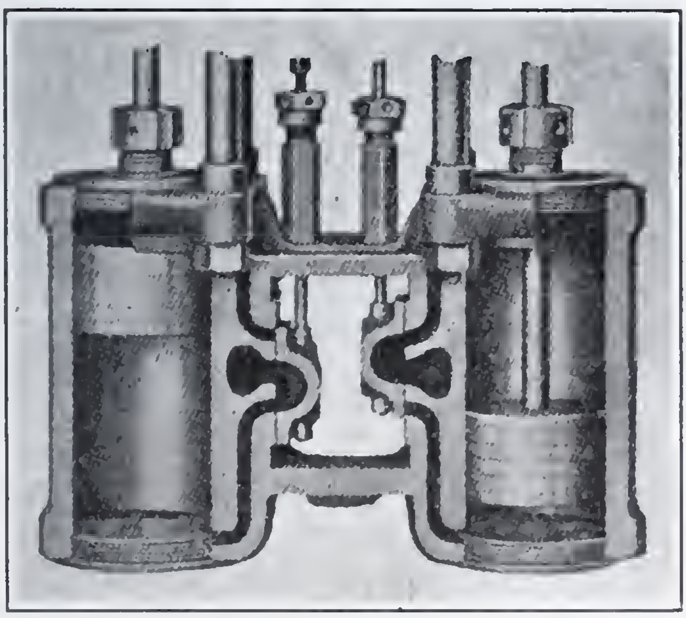


Fig. 14. Cross-Section Through Stanley Cylinders.

The valves (Fig. 14) are plain unbalanced D slide-valves driven by Stephenson valve-gear. A pedal reverses and gives a range of cut-off, ahead, from zero to seven-eighths of the stroke.

The crank-pins and main bearings are roller-bearings. See Fig. 15.

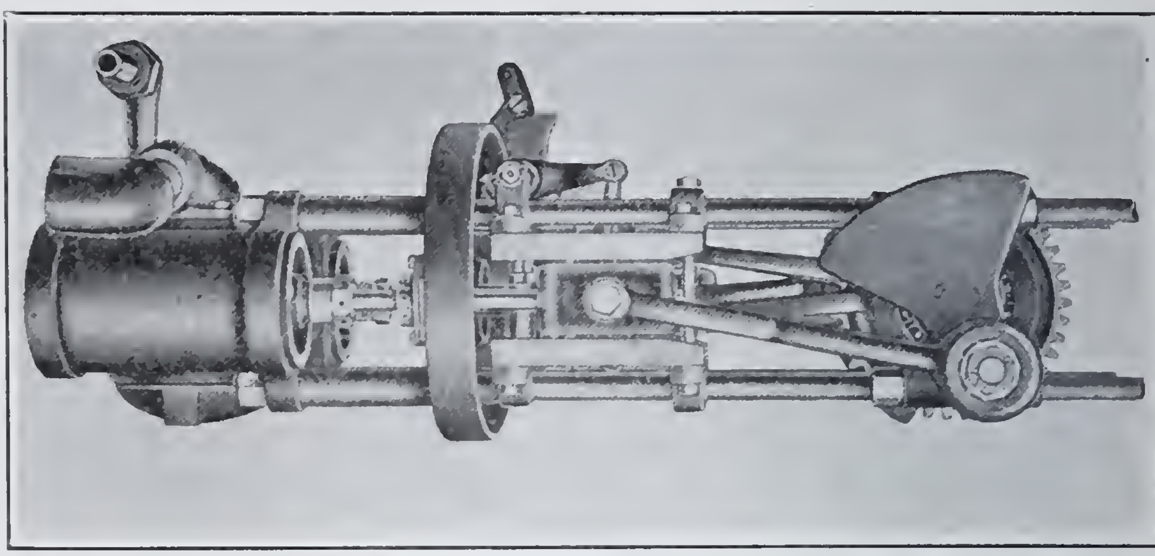


Fig. 15. Side View of Stanley Engine.

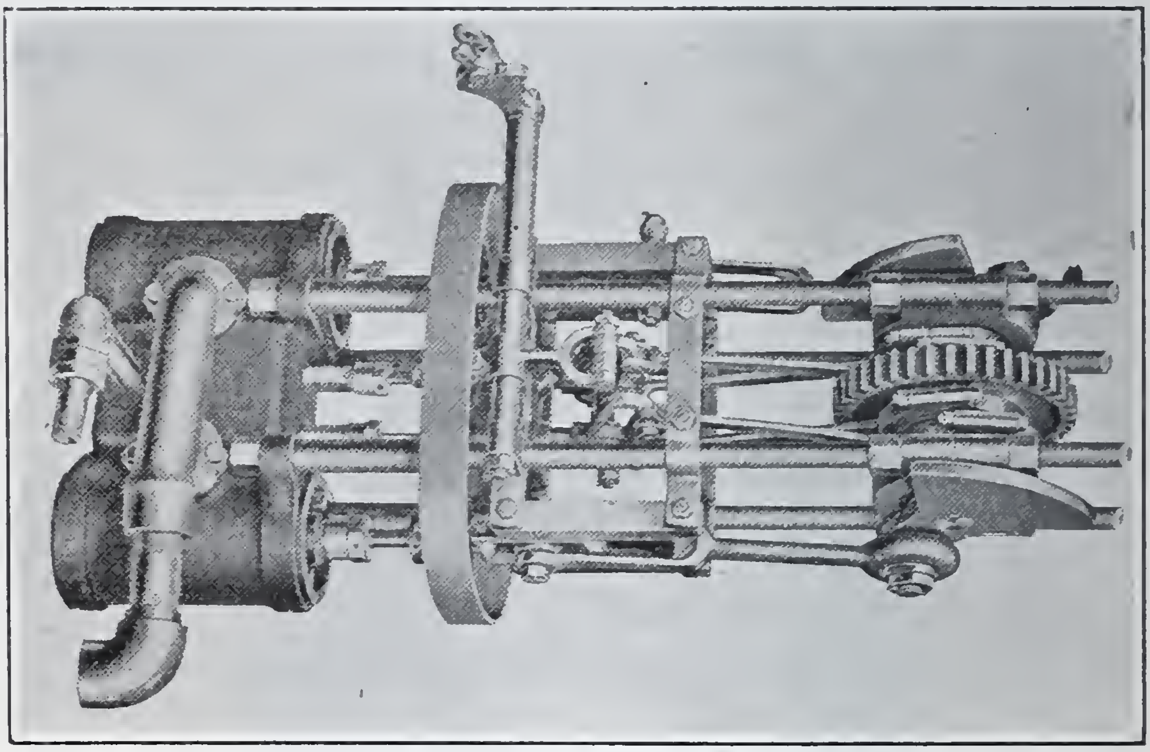


Fig. 16. Plan View of Stanley Engine.

The engine (Fig. 16) is hung horizontally and forms a torsion member for the rear axle, the cylinder end being suspended by a flexible steel plate.

The exhaust from the engine is condensed in a condenser, consisting of a gas car radiator, and returns to the main water tank to start the circuit again. The water tank for the 20-horse-power car holds 24 gallons, giving 150 to 250 miles according to road. load, and driver.

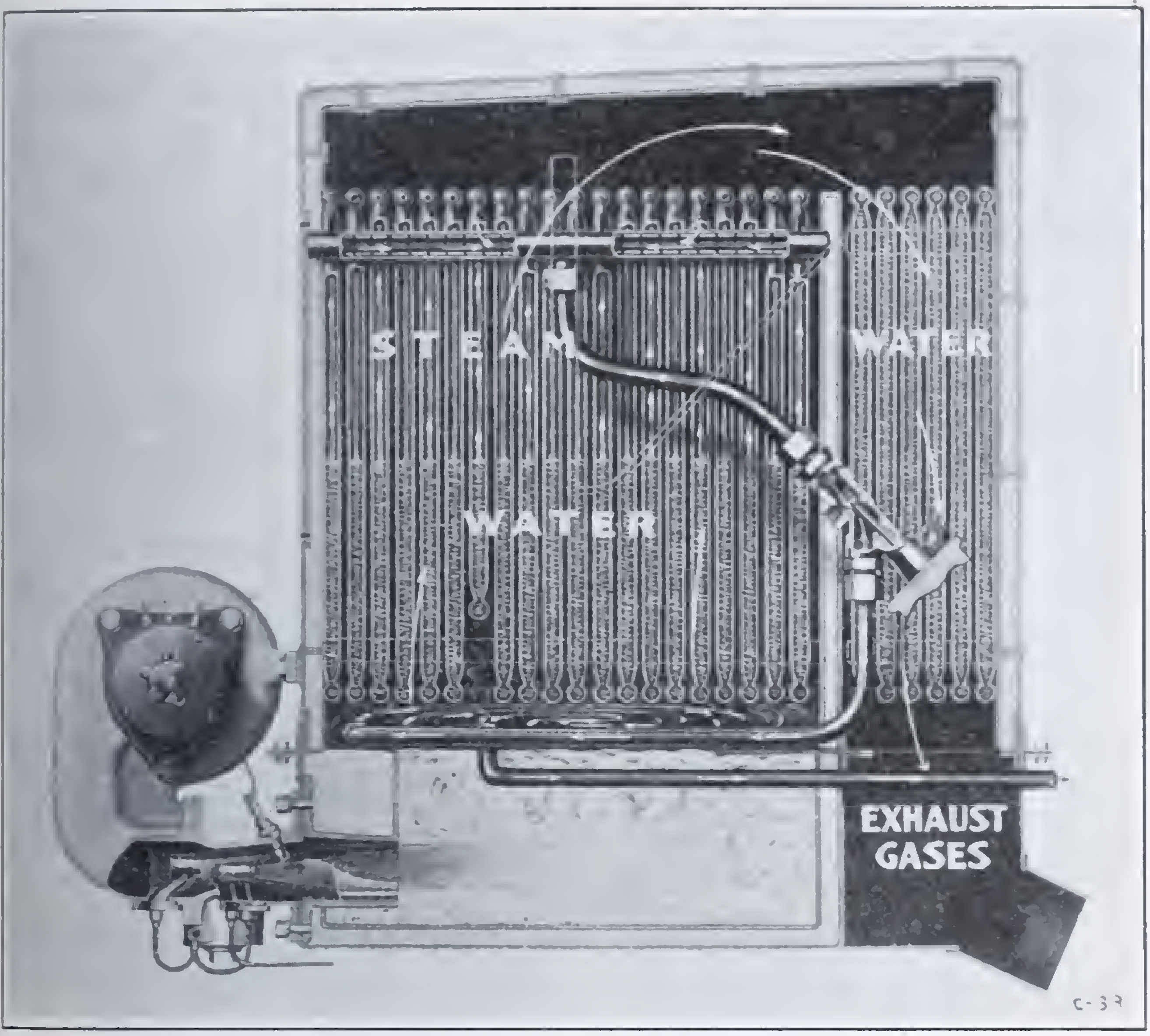


Fig. 17. Cross-Section of Doble-Detroit Boiler.

A long period of experimentation has resulted in the present Doble steam generating system (Fig. 17) which is similar in theory to the flash boiler, yet in appearance is more like the water-tube boiler, having a water level in the evaporating zone. It consists of 26 sections placed in a planished steel casing insulated with kieselguhr. Each section is made of cold-drawn seamless steel tubing of 0.75-inch diameter, 16-gage metal. Twenty of these sections are used for the generation of steam, and the remaining six are the preheating or economizer sections. The generating sections consist of 20 vertical tubes connected at top and bottom by horizontal headers. The vertical tubes are swaged at both ends to about 0.375 inch, and are welded into the horizontal headers by the autogenous acetylene process, thereby making the section, in effect, one piece of steel and actually stronger at the welded joints than in the tubing itself. The six economizer sections are

like the generating sections, except that they have 16 instead of 20 vertical tubes.

The generator is designed for a working pressure of 600 pounds and the safety-valve is set for 1000 pounds. Each section is tested to withstand 5000 pounds pressure. When sections have been subjected to a destructive test in laboratory experiments, observations have shown the rupture of a tube to occur only at cold-water pressure ranging from 8000 to 9500 pounds, and when a rupture did occur it was invariably at a point remote from the welds. The boiler weighs about 520 pounds.

Directly below the generating sections is the combustion chamber (Fig..18) and below the economizer is the exhaust for

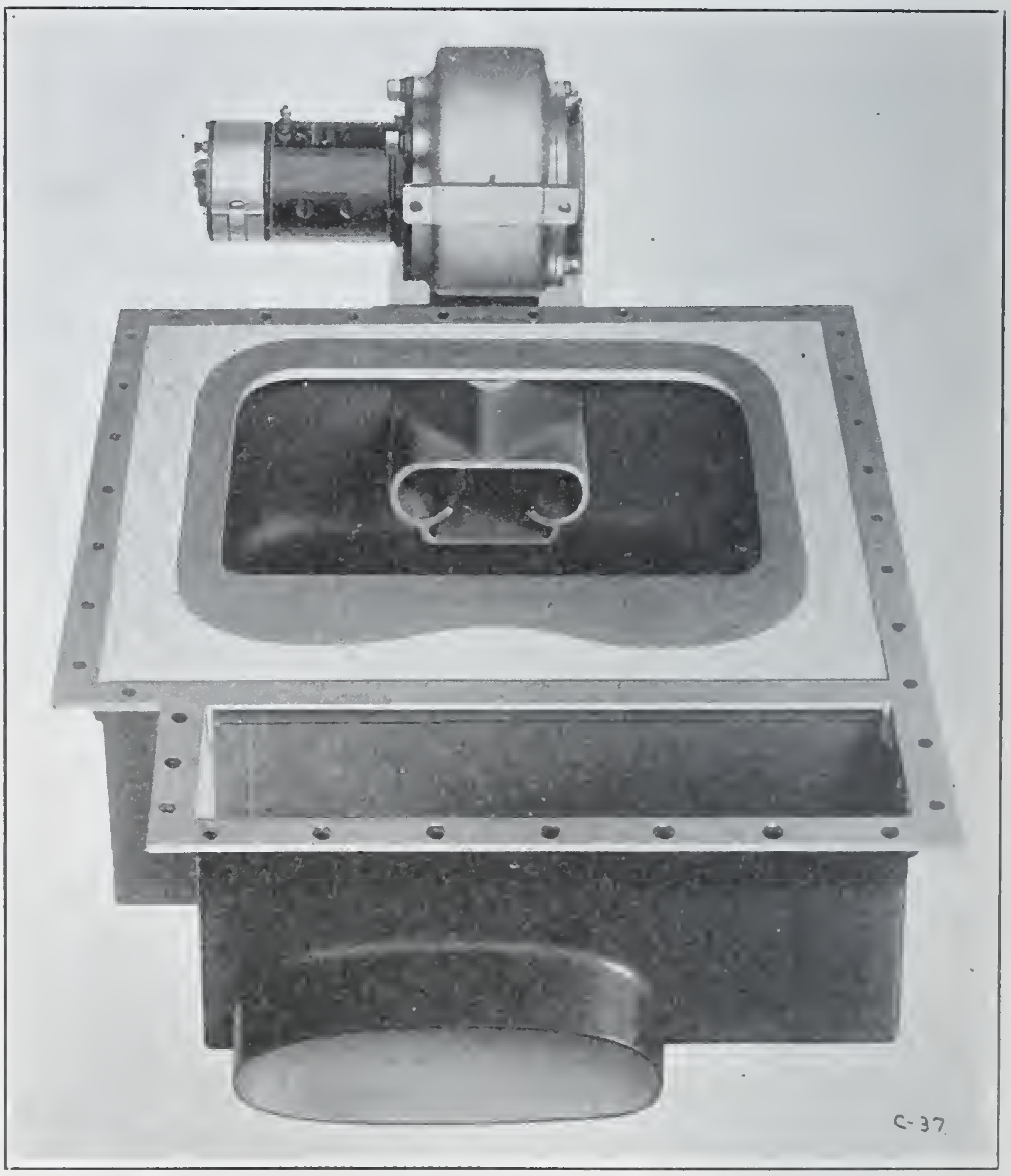


Fig. 18. Plan View of Doble-Detroit Combustion Chamber.

the gases of combustion. A bridge wall of kieselguhr divides the two sets of sections. A manifold, through which water enters, connects the lower headers of the economizer sections. The water leaves by a similar manifold at the top and is led to a manifold connecting the lower headers of the evaporating sections. The steam leaves the upper headers and is conducted through a fourth manifold to the throttle-valve.

Besides being absolutely free from any danger of explosion a boiler of this construction can be manufactured cheaply, and any damaged section can either be easily and cheaply replaced or can be isolated in a few minutes by blanking it off until it can be replaced. The excellent heat transfer conditions, due to the close and regular heating surfaces, virtually duplicate those of a fire-tube boiler, while a large reserve of water close to steam temperature is always present. The flow of the water, counter to that of the gases, with no circulatory flow, and the all-steel construction show a distinct similarity to the flash type. Water is supplied to the boiler by a crank-driven pump, and the water level is maintained about half way up the generator by an automatic regulator. See Fig. 19. If the water level falls below normal, the regulator tube will fill with steam, the expansion of which closes a by-pass valve, thereby allowing water from the pump to enter the boiler. As soon as the level reaches normal, the regulator tube fills, through an outside pipe, with water which has not been in circulation in the generator and is therefore comparatively cool. The regulator tube at once contracts, permitting the valve to open and all water to be by-passed back to the supply tank.

We now come to the two most important factors in the operation of this generator:

1. The ignition system, which permits the driver, seated at the steering-wheel, to cause the lighting of the fire in the boiler by the turning of an electric switch.
2. The small combustion chamber in which enough fuel can be consumed to supply the requisite number of heat units to generate and maintain at all times a sufficient steam pressure for driving the engine under whatever road conditions may be encountered.

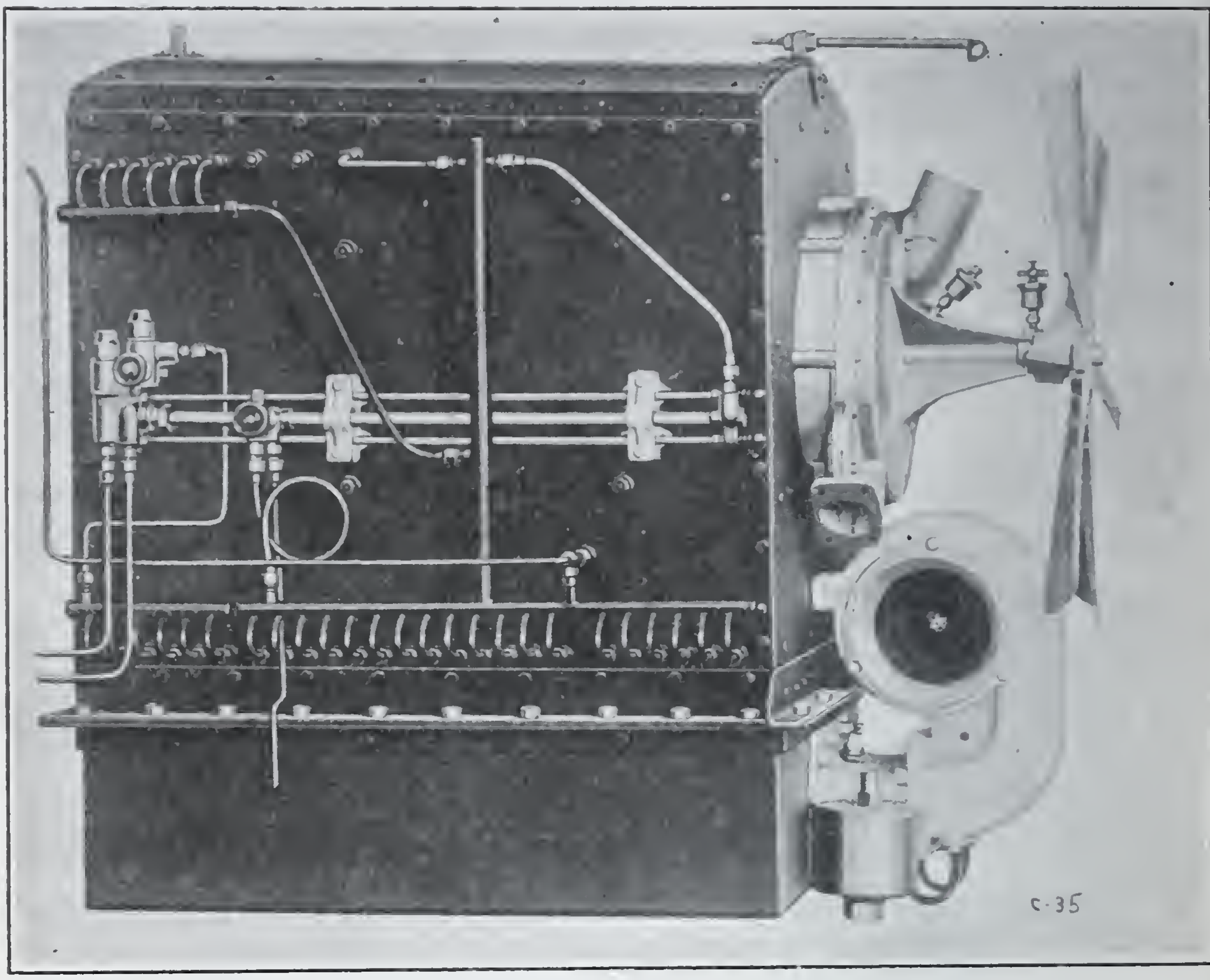


Fig. 19. Side View of Doble-Detroit Boiler, Showing Water Regulator, Fan Driven by Exhaust Steam-Turbine, and Fuel Blower Driven by Electric Motor.

In order to start the car, it is necessary to have four pounds of air pressure on the fuel tank; kerosene is then delivered to the float chamber which is located alongside of the spray nozzles in the venturi tubes of the blower. This four pounds of air pressure is first obtained by means of a hand-pump on the instrument board, but when the car is running, it is maintained by a small air-pressure pump operated by a cam on the rear axle shaft. The storage battery is charged by a generator driven through a gear on the axle shaft. See Fig. 20.

When the switch on the steering column is closed, the current passing through a solenoid starting valve starts the blower motor. The blower, revolving at about 2300 r.p.m., creates a forced draft which by aspiration feeds the kerosene from a float chamber with a proper mixture of air through what are termed the two running nozzles. At the same time that the blower is

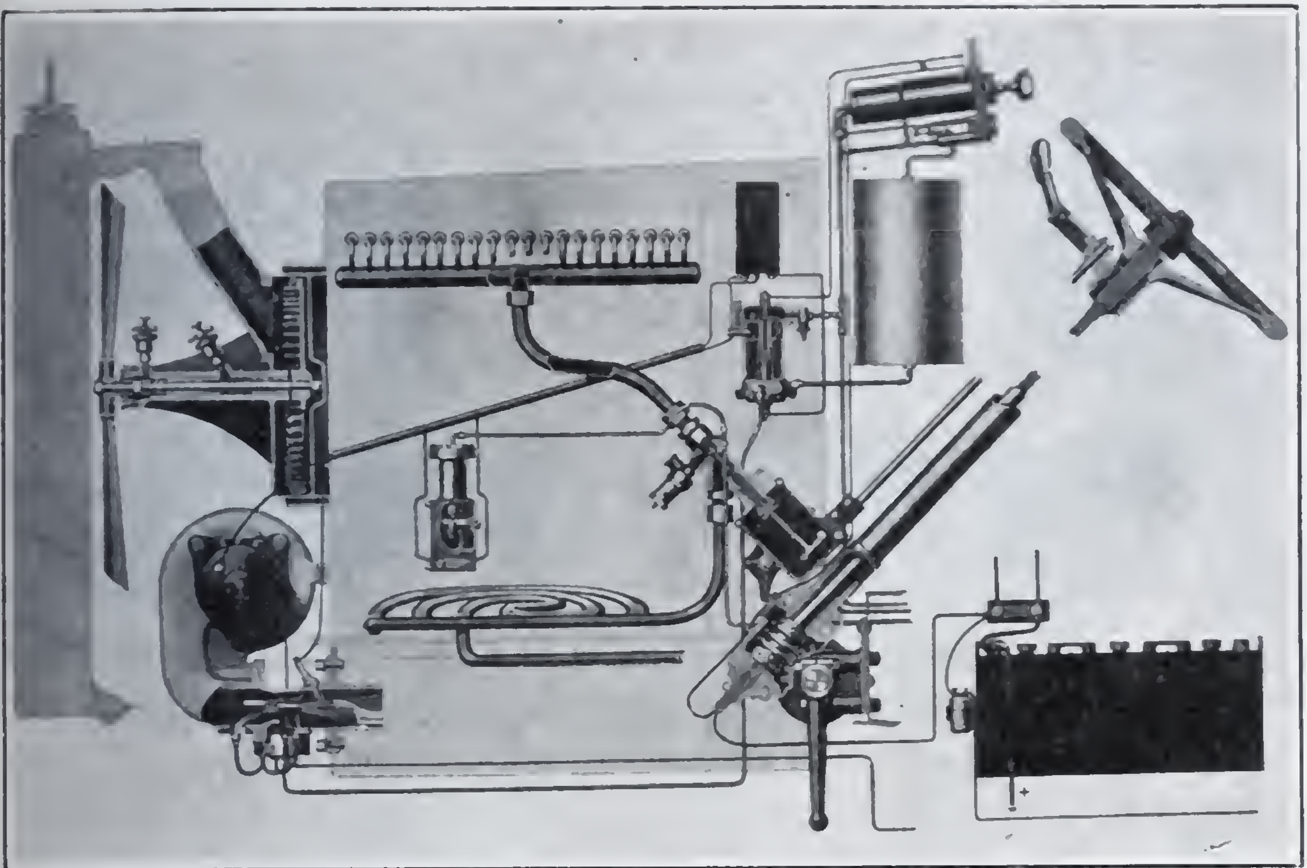


Fig. 20. Assembly of Doble-Detroit Ignition System.

started by the current passing through the solenoid, the latter magnetizes and raises a small valve which releases air under four pounds pressure from a small auxiliary air tank connected with the solenoid valve. This charge of air rushes to a starting nozzle located between the two running nozzles, aspirating kerosene through the starting nozzle with a rich mixture of air.

Directly in front of the starting nozzle is a spark-plug. See Fig. 21. At the time the air pressure is released through the solenoid valve, it acts on a diaphragm in the solenoid and makes an electric contact with a spark-coil so that, as air and kerosene are passed through the starting nozzle in an atomized condition, the spark ignites the rich mixture, and this primary flame ignites the lean mixture which is being fed by the blower through the running nozzles. The duration of the primary flame at the starting nozzle and the duration of the spark are governed by the time required to exhaust the air supply in the auxiliary air tank at the solenoid. This occupies the space of about one and one-half seconds; but the motor is still driving the blower so that the fuel through the running nozzles, which has been ignited by the flame of the starting nozzle, continues to burn in the combustion chamber.

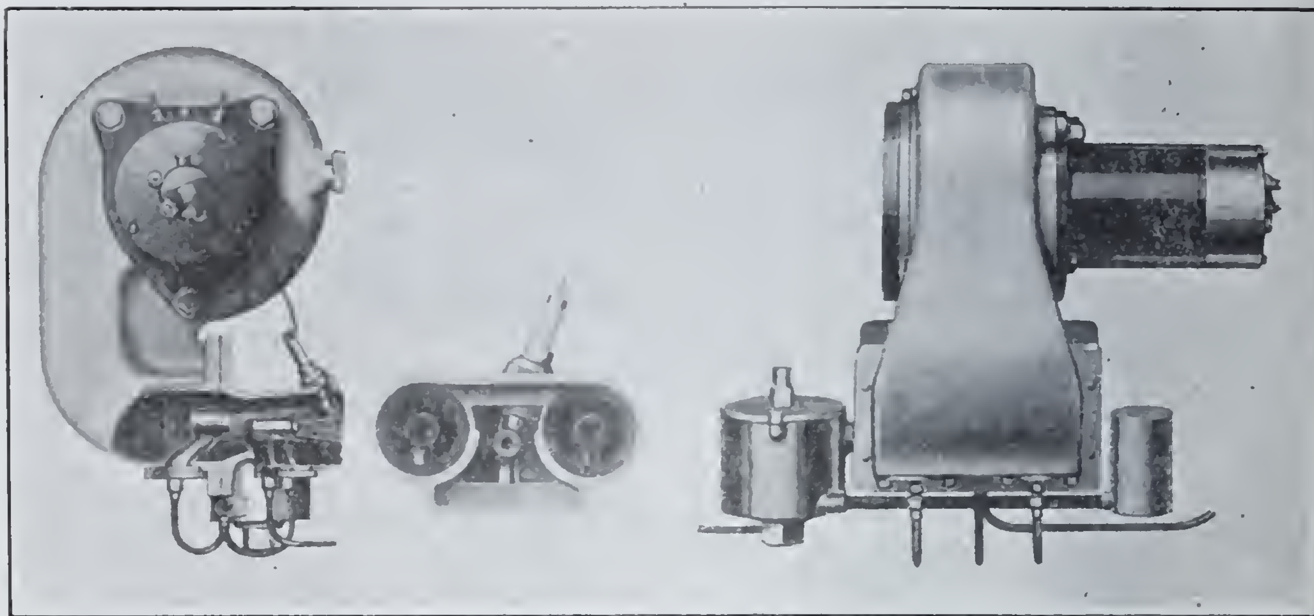


Fig. 21. Fuel Blower of Doble-Detroit. Section Showing Nozzles and Spark-Plug.

By a simple automatic regulator, the current to the motor is shut off when the steam pressure has reached 600 pounds, and the fire goes out in the combustion chamber. At the same time, the auxiliary air tank is recharged by the solenoid valve dropping to its seat, due to the breaking of the current, so that the system is ready to repeat the starting operation which is now being controlled by the steam-pressure regulator. When the steam pressure drops to about 550 pounds, contact through the solenoid is again made, and the fire is lighted. This requires no attention on the part of the driver, and, as long as the switch on the steering column is closed, the fire continues to go on and off according to the steam pressure. When driving over ordinarily level roads, the fire will be on about one-third of the time.

The space available for a combustion chamber or fire-box for a steam-boiler is limited in a steam-driven automobile—so limited, in fact, that without changing the conventional lines of the modern automobile hoods, a fire-box 20 inches square and 8 inches deep was as large as could be employed.

It is well known that if the flames from burning fuel be permitted in contact with the flues or water-tubes of a boiler, the products of combustion will readily form smoke and soot, and that the tubes will soon become so heavily coated as to reduce materially the evaporating capacity of the boiler.

When oxygen in the form of air is supplied with the atomized liquid fuel, sufficient not only to support complete combustion but also to produce a temperature sufficiently high to insure ample steam pressure under all possible demands, an immense body of flame results. The main problem, therefore, was to construct a fire-box of such shape that the sprayed fuel and air could be injected into it and that the flaming combustible could absolutely be retained within the limits of the combustion chamber and not come in direct contact with the water-tubes of the boiler.

The method of burning the fuel consists in projecting a stream of sprayed kerosene and air in sufficient proportion to support complete combustion and with such force as to compel the stream to remain in a horizontal plane. The stream is doubled upon itself in a horizontal plane to confine it in parallel planes until combustion is complete. This has been accomplished by arranging the shape of the combustion chamber so that the fire is almost completely confined in the fire-box, and does not come into direct contact with the boiler tubes.

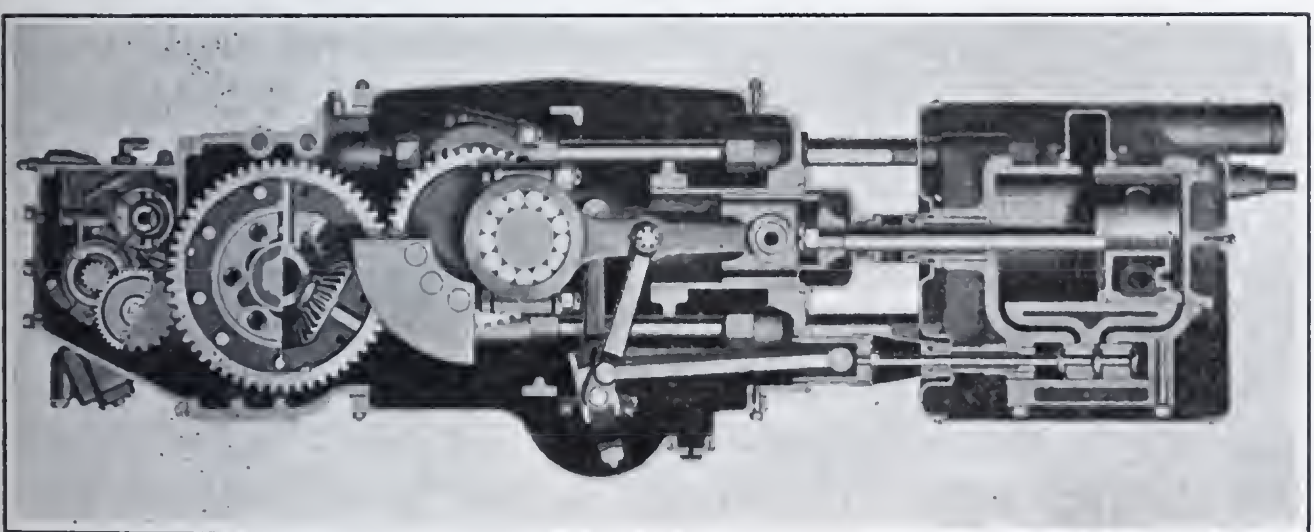


Fig. 22. Longitudinal Section of Doble-Detroit Engine, Showing Differential Gear, Pump, and Electric Generator Drive.

The engine (Fig. 22) is exceedingly simple and contains but 11 moving units. The dimensions of all the working parts are ample to insure uninterrupted service under maximum conditions of load. The engine is five-inch bore, four-inch stroke, of the two-cylinder, single-expansion, double-acting type. The uniflow principle is employed, in order to provide the high expansion desirable, with a noiseless valve-gear and only one valve per cyl-

inder. The valve takes care of the steam inlet, while the exhaust passes out through ports, uncovered by the piston at the end of the stroke. It is thus possible to secure cut-off at three-sixteenths of the stroke. This cut-off is used for all ordinary running, and operates with perfect accuracy on either stroke of the piston. For starting or heavy pulling, a cut-off is used at three-fourths of the stroke.

Since the thermal conditions in the uniflow cylinder are practically ideal, it is unnecessary to use superheated steam, but it is desirable because it reduces the weight which must be condensed. The slide-valves are on top of the cylinder, and each is made in two pieces so that in slow running they will be lifted whenever the compression exceeds the steam-chest pressure. This makes the engine run smoothly at all speeds, and also allows a high compression at higher speeds and steam-chest pressures.

The valves are actuated by a specially designed valve-gear, which dispenses with the need for eccentrics, thus making a one-piece crank-shaft possible. This gear gives an excellent steam distribution, and also reverses the engine without additional devices. It is a simplified form of the Joy valve-gear, from which the connecting and anchor links have been eliminated. The rocker guide is straight instead of curved. The piston-rod passes through a specially designed gland, which is made in such a manner that no steam can blow by it. On account of the long bearing surface, there is practically no wear, and repacking is rarely required. The crank case is an aluminum casting, and contains the moving parts of the engine, except the pistons and valves. The differential is also contained in the crank case, and the taper tubes of the axle bolt directly to it, thus making the engine and rear axle one unit. The forward end of the engine is suspended from a cross member of the frame by a flexible steel strap. The crank-shaft, differential and big-end, connecting-rod bearings are annular rollers and are of such proportions that no wear can occur during the natural life of the car. All of the other bearings, such as the wrist-pin and valve-gear bearings, are hardened steel, running in hardened steel bushings.

The power is transmitted to the rear axle by means of two large spur-gears, a 42-tooth gear on the engine crank-shaft and a

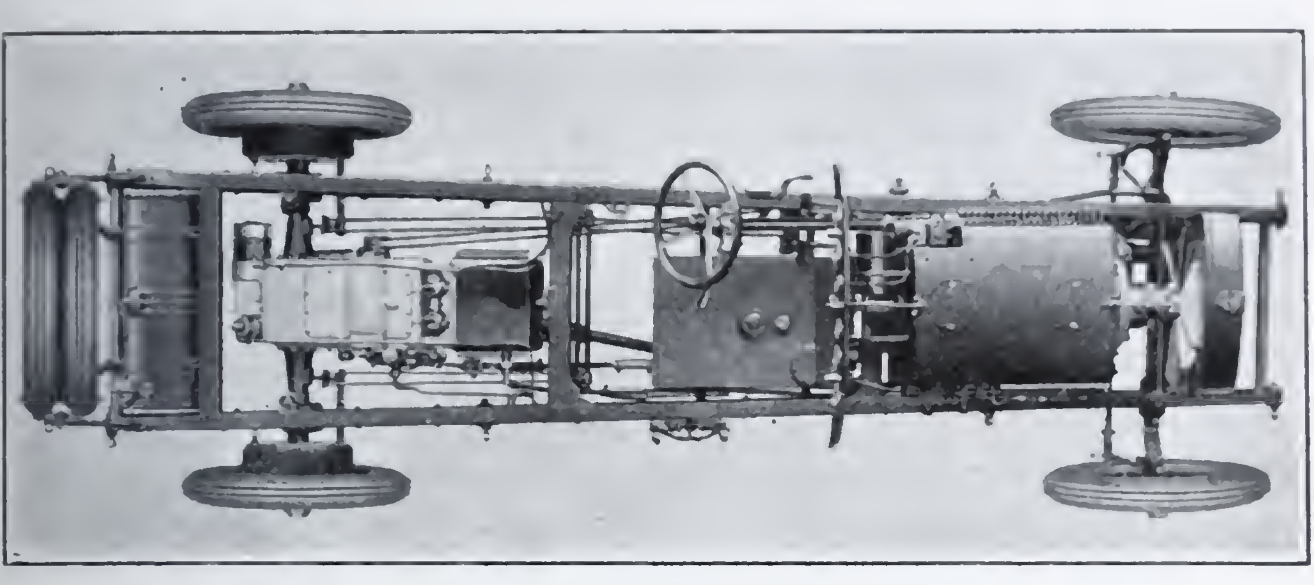


Fig. 23. Airplane View of Chassis of Doble-Detroit, Showing Complete Power-Plant.

54-tooth gear on the differential. See Fig. 23. The engine has more power than is needed to spin the wheels on dry pavement, while the car is held stationary. With the car at a standstill, on the level, with 600 pounds of steam, if the throttle is opened suddenly, the pressure will drop to 450 pounds by the time the car has attained a speed of 60 miles an hour.

The engine weighs about 240 pounds. The nominal horse-power rating is 25, but the engine will develop 70 horse-power continuously, or 132 horse-power for a very few minutes.

Gas-engine cylinder oil is supplied to the crank case of the engine. This is splashed by the crank-shaft and main driving gears and lubricates the working parts of the engine. By means of a small oil-feed pump, the oil from the crank case is also delivered to the steam-chest of the engine, lubricating the valve-seats, valve-stems and cylinders. This lubricator is set to feed one gallon for each 5000 miles.

Passing through with the exhaust steam from the engine, a small quantity of oil continuously finds it way to the water-supply tank and is fed with the water into the boiler. The oil is accordingly regularly pumped into the boiler along with the water, and far from having a deleterious effect, really performs its most valuable functions in that part of the power-plant. This oil is very thin at 490 degrees F.—the approximate steam temperature at 600 pounds pressure—and the coating of oil which forms over the entire inner surface of the boiler is consequently so thin as to

have a negligible effect upon the heat-transfer conditions.

As scale does not adhere to a surface coated with oil, the interior of the boiler remains entirely free from incrustations of scale matter, and is likewise thoroughly protected from corrosion. The second function of the oil is to coat each particle of scale-forming material as it is thrown out of solution, thus preventing one particle from sticking to another in such a way as to form a body of sufficient size to clog some restricted passage. No large amount of scale-forming material is introduced into the system since but little make-up water is required. The violent ebullition and the constant flow of the medium toward the steam outlet cause the minute particles of scale to be carried along with the steam, so that the boiler and radiator are both kept free from deposits. The scale-forming material finally reaches the water tank, where it either remains or continues to circulate through the system without any apparent deleterious effect.

The exhaust steam is carried from the engine to a small, low-pressure steam-turbine which is mounted on the front of the boiler casing. The condenser fan is on the shaft of the turbine. By the use of the turbine, a greatly increased efficiency in condensation is effected as, when the engine is working the hardest on grades or heavy roads, the turbine will be driven at an increased speed so that the fan will draw more air through the condenser at the time it is most needed, regardless of the car speed.

TEST DATA

Total tube surface in boiler	143 sq. ft.
Total tube surface in economizer	34 sq. ft.
Total tube surface in boiler and economizer	177 sq. ft.
Total water surface in boiler	118 sq. ft.
Total water surface in economizer	25.9 sq. ft.
Total water surface in boiler and economizer	143.9 sq. ft.
Total capacity of boiler	1.425 cu. ft.
Total capacity of economizer	0 333 cu. ft.
Total capacity of boiler and economizer	1.758 cu. ft.

Total capacity of boiler and economizer	10.8 gallons
Total capacity of boiler and economizer, with 11 inches water level	9 gallons
Total weight of boiler and economizer sections	450 lbs.
Actual evaporation, per hour	630 lbs.
Equivalent evaporation, per hour	765 lbs.
Equivalent evaporation, per lb. of kerosene	18.05 lbs.
Equivalent evaporation, per sq. ft. of boiler surface	7.38 lbs.
Equivalent evaporation, per sq. ft. of boiler and economizer	5.20 lbs.
Fuel consumption per minute	0.687 lbs.
Temperature of steam at boiler	515° F.
Superheat	25° F.
Gage pressure	600 lbs.
Heating surface, including economizer	146.7 lbs.
Overall efficiency	90%
Temperature of feed water	62° F.
Boiler horse-power	22.25
Temperature of flue-gas	410° F.

WATER CONSUMPTION AT 60 MILES PER HOUR

Volume of cylinder = 19.6 × 4 = 78.4 cu. in.
Volume at 3/16 cut-off, 3/16 × 78.4 = 14.65 cu. in.
Volume per revolution for two cylinders 58.6 cu. in.
Volume at 60 miles per hour or 740 r.p.m. = 740 × 58.6 = 43,400 cu. in. = 25.2 cu. ft.
Steam-chest pressure, 250 lbs.
Weight of one cu. ft. of steam at 250 lbs. pressure = 0.57 lbs. (25.2 × 0.57 = 14.3 lb. water).

GENERAL DATA

Wheels, inches	35
Tires, inches	5
Wheels, r.p.m.	576
Engine, r.p.m.	740
Ratio of dynamo speed to rear-axle speed	9.43 to 1
Ratio of dynamo speed to engine speed	7.33 to 1
Wheels, r.p.m. at 30 miles per hour	228
Engine, r.p.m. at 30 miles per hour	370
Dynamo, r.p.m. at 30 miles per hour	2712

PROBABLE TREND OF FUTURE DEVELOPMENT.

The steam generator and combustion system will be simplified, though the trend has been toward complication up to the present. A distinctly new type of boiler is now the subject of

experiments and promises large capacity with very low weight and a much sturdier construction than those discussed in this paper. This boiler is made possible by a new application of combustion. The engine will no doubt stand practically as it is, except that for the larger trucks it may be advisable to use a separate engine to drive each rear wheel through an internal gear on the road wheel, meshed into a pinion on the end of a short crankshaft. This is not new, but does away with all differential-gear and live-axle troubles, and can be made to give most of the advantages of a locked differential. The pumps will no doubt be improved and made into more compact units.

With the large, heavy trucks, power steering and power braking have both been used successfully and on a steam vehicle add almost nothing to complicate it.

Even an ideally efficient storage battery would not permit an electric car that could rival the performance of a well designed steam vehicle, because it would not have the extreme reserve capacity necessary for bad conditions, unless the electric motor were made abnormally large, in which case it would be inefficient at normal loads. The electric car is also dependent on the charging station.

DISCUSSION

Mr. E. W. Pittman:* What is the ability of the steam cars to climb hills, for example, in McKeesport, with 600 pounds of steam?

Mr. F. L. Egan: In regard to the ability of a steam car to climb a hill, I will state that there is never any question of power to climb any hill on which an experienced driver would care to risk his passengers. This applies to any of the three cars made in America. Please refer to my statement in the description of the Doble-Detroit engine. Also to the test of the White steam truck on the St. Louis levee. It is very easy to start or stop on the steepest hill without any sign of shock or jar.

Mr. W. B. Spellmire:† How do you account for the great preference for the gas car in preference to the steam car?

Mr. F. L. Egan: At the time the automobile came into being, especially in this country, the entire demand was from wealthy sportsmen. There was the extreme novelty of a machine which would travel at a good speed over common roads, and which obtained its power from the fuel, direct. It is a sad truth, that in the early days of the automobile business, the manufacturer sold his experiments at high prices. At this time there were four gas cars on the market, selling for an average of 10 per cent. more than the Stanley steam car, and not able to give anywhere near the performance of the steam car. The life of these early gas cars was approximately one-fourth that of the Stanley steam car of that time.

The answer is that the purchaser of that time was suspicious of steam and afraid of it, and we must remember that he was not educated in motor vehicle mechanics as the purchaser of to-day generally is.

*Chief Engineer and Manager, John Eichleay, Jr. Co., Pittsburgh.

†Manager, General Electric Co., Pittsburgh.

We all know how the comparatively simple, single-cylinder gas car, has developed into the amazingly complicated twin-six car, with its electric generator and starting motor, batteries ignition, all its complicated thermo-controls, etc., until it is a wise service-station personnel that can successfully cope with trouble in its own product.

With the first gas cars the purchasers received an elaborate instruction book which went into a great deal of detail. With the modern car you are instructed to see that you have plenty of gas in the tank, that the oiling system is filled, and the spark plugs are clean; and, then, if you have trouble, go to the nearest service station, where they will fix it up and charge you a dollar and a half an hour for an uncertain number of hours.

MR. F. C. FAIR:* Will you describe the indicator card of the Doble engine?

MR. F. L. EGAN: At one quarter cut-off, it is about the same as a good diagram from a low-speed releasing Corliss engine, except that possibly the release is not quite so good and the compression, of course, runs much higher. At the maximum cut-off, the card approaches a rectangle, the admission line and cut-off still being very good.

It is rather difficult to indicate an engine of this size satisfactorily and especially so in the work I have done, because the piston speeds have been high—a maximum of approximately 1300 feet a minute. We have done some indicating, using a beam of light on a sensitized, photographic film, but the results are of doubtful value. Most of the progress has been from mathematics and the careful adjusting of the valve-gear design to an ideal card, leaving nothing to be accomplished by adjustment after the engine is built. A duty of one horse-power hour on 16 or 17 pounds of water, with plant up to speed and capacity, can be considered normal for any modern vehicle plant either English or American.

*Engineer in Charge of Tipple Construction, Pittsburgh Coal Co., Pittsburgh.

MR. F. C. SCHATZ:* It may be of interest to know that a firm in Pittsburgh experimented with steam cars commercially, beginning about December, 1903, these experiments continuing for about four years. It may also be interesting to know just how they were introduced.

Two promising young men in this city learned of a steam car that was made in Buffalo, for which they had reason to believe there was a future. They were looking for such people as the speaker refers to, who would buy the cars and pay liberally for the maintenance, in order that the manufacturer could continue to do the experimenting. When they presented the proposition to us, our viewpoint was that they asked too much money for the cars, and we doubted whether they were really practicable. However, they sold them on a very broad promise that they would do all they claimed or we would not have to pay for them. That sounded reasonable, and we started to use them in December.

On account of snow, we found we could not make them operate successfully, because the wheels would spin. We burlaped the wheels, wrapped ropes around them, and eventually tried chains, and finally did succeed in overcoming the traction problem. Before long we met with boiler-tube trouble. During these trials the manufacturer stood by his agreement, until we decided he had done his part, after which we paid for the cars. We were determined to give steam cars a fair trial, but it was very much like taking hold of the hot end of the poker. We held on for four years and finally succeeded in making them mechanically practicable, but they were financially impracticable, and we changed to gasoline cars.

As far as flexibility is concerned, they were very satisfactory. We had no difficulty in getting drivers who could handle the cars, if they were in fair working condition, and there were no hills around Pittsburgh which we could not climb as well as we can to-day with gasoline cars.

The author has pointed out many improvements made on the present steam cars over the earlier types, which would give rea-

*Superintendent of Buildings and Equipment, Joseph Horne Co., Pittsburgh.

son for the belief that steam-driven trucks, especially those of larger capacity, may eventually be used for trucking purposes.

Mr. L. C. Frohrieb:* Is there any possibility of using fuel oil in a steam-driven car?

Mr. F. L. Egan: Yes. Both the Stanley and the Doble-Detroit cars use either gasoline or kerosene or any mixture of the two.

When we were experimenting with steam trucks, we used fuel oil, Texas crude, and gas coke. There is no difficulty with oil, except that it has a bad odor and the burner is noisy. It costs more than coke and is harder to handle. The ten-ton vehicle, mentioned as being in use up to two years ago, burned coke. The stoking was almost automatic, by merely pressing a pedal. Both the steering and the braking were handled by power. The front wheels could be turned through the entire range by the pressure of two fingers on a six-inch lever.

Mr. George H. Danforth:* You were speaking of using wood tires on trucks. Were there steam-driven trucks with wood tires running in Chicago six years ago?

Mr. F. L. Egan: I can not say as to that.

Mr. George H. Danforth: I think I saw one on Adams Street. It probably belonged to some of the warehouses in that district.

Mr. F. L. Egan: We had an experimental truck running as a demonstrator in Chicago in 1903 and 1904. The driver was inexperienced, being a locomotive fireman. The demonstration charges included all fixed charges including a heavy insurance, maintenance, fuel, wages and 15 per cent. profit on the whole. When we discontinued the demonstration, we found our customer would have been pleased to continue indefinitely.

*Secretary, Federal Engineering Co., Pittsburgh.

†Structural Engineer, Jones & Laughlin Steel Co., Pittsburgh.

Mr. F. M. Van Deventer:* What are the expansion conditions under which these machines operate? Is the vacuum obtained well up on the mercury column, or does the radiator merely condense the steam at around atmospheric pressure?

Mr. F. L. Egan: There is no vacuum.

Mr. F. M. Van Deventer: In regard to the disposition of waste flue-gases, I would understand that the motor-driven fan on the Doble creates enough pressure to force the products of combustion through the boiler and economizer. The Stanley burner as shown seems to depend upon the aspiration of the vapor jet to draw in air. Is this sufficient to force the gases through the boiler, or is there any other source of motive force corresponding to the Doble motor-driven fan?

Mr. F. L. Egan: Your understanding is correct. The Stanley burner aspirates the air for combustion and the gases pass out through a vent pipe under the floor boards of the car.

Mr. W. B. Spellmire: How much superheat do they use in these cars?

Mr. F. L. Egan: The most I have ever checked was 120 degrees F., but it usually runs about 60 or 70 degrees F. We got 120 degrees by an arrangement of the boilers which we were afraid would make trouble in the user's hands so we reduced the maximum attainable.

Mr. L. C. Frohrieb: Are any of the coal- or coke-fired machines now in use in this country built here?

Mr. F. L. Egan: So far as I know, there are no American built machines now in use.

Mr. L. C. Frohrieb: What is the reason they are not made in America?

*Engineer, National Tube Co., Pittsburgh.

Mr. F. L. Egan: It seems to be that capital cannot be interested. Most people consider it an innovation. At the start of the European war, two of the English steam wagon builders were swamped with orders from America, until it reached the point where they merely sent a catalogue in reply to inquiries. The English colonies take all the English wagons that they can produce with their present methods. The Terminal Transportation Company of New York at one time stated they could use 100 machines similar to the one shown to-night. When we were building our experimental trucks, the St. Louis Transfer Company was in the market for 125.

Mr. John A. Ferguson:* Would it be possible to get up those coke units for plowing machinery?

Mr. F. L. Egan: I intended to make that clear in my paper, but due to the fact that this paper is about 30 per cent. of the total as prepared, it does not cover the field it should.

The steam wagon of to-day is a development of the old English plowing engine that has been in common use for many years. The English coal- and coke-fired machines were in use for plowing long before we had steam threshing machines.

Mr. John A. Ferguson: Gasoline is so hard to obtain and so expensive, that I would think there would be quite a field for a steam machine.

Mr. F. L. Egan: I mentioned the fact that we operated a truck on corn-cobs. This was sold to a Kansas concern, which dealt in building materials. Hard coal was very expensive, and the only other fuel easily obtainable was corn-cobs. We finally sold them a wagon under a bond to deliver a certain performance with this fuel, and succeeded.

Mr. D. J. Fleming:† Are any cars operated with bagasse?

*Secretary-Engineer, Pittsburgh Building Code Committee, Pittsburgh.

†Engineer, The Koppers Co., Pittsburgh.

Mr. F. L. Egan: I don't know. I have used it both dry and wet under stationary boilers and it is satisfactory fuel, but its bulk would prevent its use as a wagon fuel.

Mr. D. J. Fleming: Don't they compress it?

Mr. F. L. Egan: I have not seen or known of its use in briquet form as a fuel for sugar-mill plants. In briquet form it would be much superior to corn-cobs.

Mr. D. J. Fleming: In countries—especially South America—where sugar-cane is extensively cultivated, bagasse has been used instead of other fuels which are very expensive—coal, for instance, $20 a ton. This, of course, applies to steam-operated trucks for hauling sugar-cane to the mills.

Mr. F. L. Egan: The regulation would not be very difficult, and in briquet form it would make a satisfactory fuel for steam wagon use.

FACTORS WHICH DETERMINE THE SELECTION OF MOTORS FOR MAIN ROLL DRIVE

By G. E. Stoltz*

Considerable progress has been made in the development of higher-grade steels in recent years, not only by introducing certain alloys, but by the treatment during the process of manufacture. When electrical manufacturers were first interested in building motors to drive the main rolls, it was felt to a large extent that it was necessary only to furnish a motor which was designed solely to develop adequate power at some given speed. Further knowledge of these applications indicated that the motor manufacturer could assist in the proper treatment of the steel during the rolling process by designing apparatus with the idea of making the driving equipment flexible so that its performance could be changed from time to time to suit the different types and sizes of steel being rolled.

The shaping of metal is accomplished by exerting a pressure greater than the yielding point of the metal at the particular temperature at which it is being rolled. Fig. 1 illustrates the physical properties of ordinary steel up to a point where the metal becomes plastic and loses its elastic properties. In soft steel, this occurs at about 900 degrees C., the same steel melting at about 1500 degrees C. It is with the temperature within these limits that we are concerned in the process of displacing metal and rolling hot steel.

As compared with ordinary steel, special steels, as a rule, have a lower melting temperature, as well as a higher temperature at which they lose their elastic properties and become plastic. Considerably more care is required in rolling these special steels, not only due to the lower temperatures to which they are heated, but also due to the higher temperature at which they become plastic, both of which decrease the range in which the rolling process must

*General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

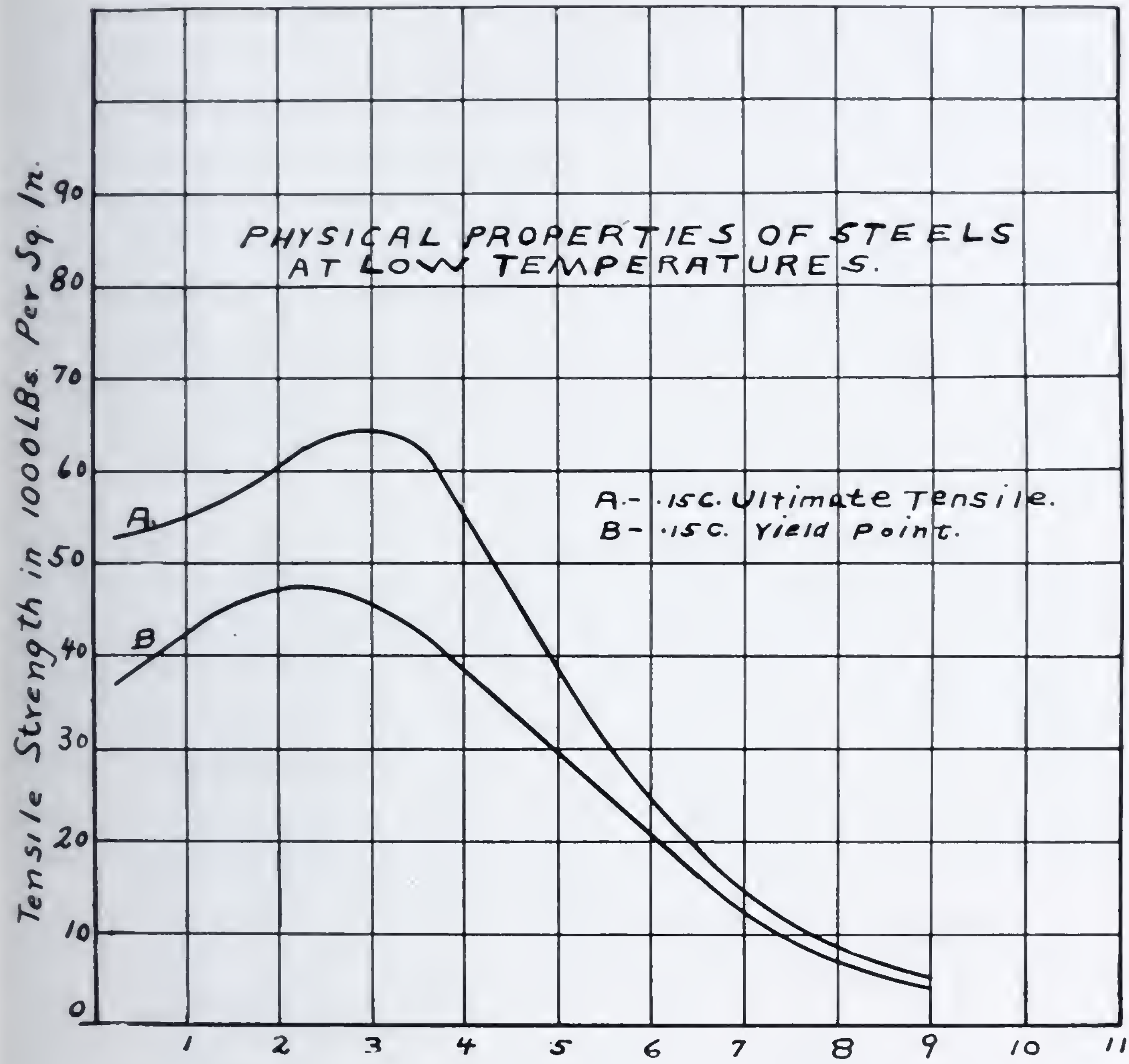


Fig. 1. Physical Properties of Steels at Low Temperatures.

be completed. When estimating the power required to roll alloy steels, we can under no circumstances be expected to use as high a temperature as is customary with wrought-iron or low-carbon steel, and the rolling process cannot be continued to as low a temperature.

As long as the steel is hot and is highly plastic, it is possible to take heavy drafts and displace the metal at high speeds without exerting great pressure; but, in any case, the speed at which the metal is displaced should not exceed its natural rate of flow. This, of course, varies with the character of the steel and its temperature. The action of steel is similar to that of oil in that its natural rate of flow decreases as it becomes cool, and any effort to exceed the natural rate of flow of hot metal will be injurious to the product. The rate of flow of the metal is influenced by the

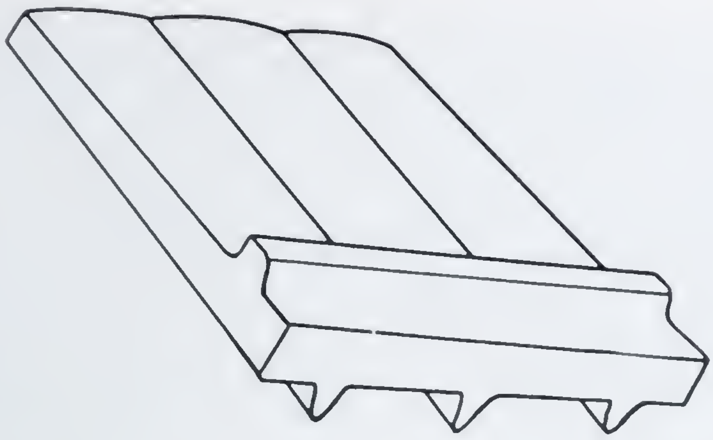
amount of reduction and the speed of the mill, so that both must be taken into consideration when comparing the rate of displacing the metal. The use of an adjustable motor will permit the selection of the proper speed, so as to allow correct drafting at all times.

There are also special steels having certain properties which make it necessary to draft the metal light during the first passes, regardless of the temperature. This practice of taking light drafts at first, and then making the later passes heavier is contrary to what we would naturally expect, but this method of treatment is due to the chemical properties, and not due to the change in temperature of the steel.

Muck-bar piles must not only be heated to a temperature which will permit easy flow of metal, but during the first few passes it is required to weld the individual bars together to obtain a homogeneous product This welding process is accomplished much better at a slow rate of rolling, and for this reason it is better to provide a motor which will drive the mill at a low speed during the first passes, and then at a higher speed during the latter passes, after the welding process is accomplished.

These are some of the factors which have led to the selection of adjustable-speed motors in preference to the constant-speed motor which would be adequate if ability to produce power were the only consideration. Such motors are also often selected where it is desired to roll a wide range of sizes on the same mill, the slower speeds being used for the heavy material, and the higher speeds on the lighter sections. An adjustable-speed motor can not only be regulated to obtain the most suitable speed desired for rolling the different sizes of sections, but a variation can be effected when it is desired to obtain a welding effect, or to regulate the flow of the metal due to different temperatures, physical properties, or to some irregularity in its cross-section.

Fig. 2 shows a tie-plate section where it is necessary to roll risers on the plate during the last pass. This is accomplished by supplying the finishing rolls with recesses which must be filled out completely during the last pass. This involves a considerable flow of metal at a time when it is comparatively cool, so that the speed during this last pass must be limited to a greater extent than would be necessary if the risers were omitted. With an



NORMAL DIRECTION OF ROLLING. ☞

Fig. 2. Typical Section of Deformed Tie-Plate.

adjustable-speed motor, it is possible to slow the mill down to a point where the proper flow can be obtained to fill out the risers. This most desirable speed can be obtained only by experimentation and by examination of the steel after it is finished, as it is naturally desirable to keep the mill up to as great a speed as possible in order to maintain the temperature of the metal. If a constant-speed motor were used, it might operate at the right speed for some one particular product and be too high for some sections, and too slow for others. If too slow, the metal would cool off unnecessarily, or in some cases by the time it reached the finishing pass the metal would have lost its plastic properties and it would be practically impossible to obtain the proper flow into the recesses of the rolls, regardless of the speed.

Several well-known systems of obtaining adjustable-speed, alternating-current motor equipments are now on the market, one of them being the constant-horse-power, rotary-converter system as shown in Fig. 3. These equipments are usually designed with a speed range of 1.5 to 1, and are controlled by adjusting the field rheostat of the direct-current machine, which is on the same shaft with the main alternating-current motor. The operation is the same as obtained on an adjustable-speed, direct-current, machine-tool motor. The field is strengthened to slow the set down, and in so doing its torque increases, which makes this scheme particularly well adapted for a large majority of mills, since the heavy material requiring the greatest torque is rolled at the low speed and the light sections at the high speeds.

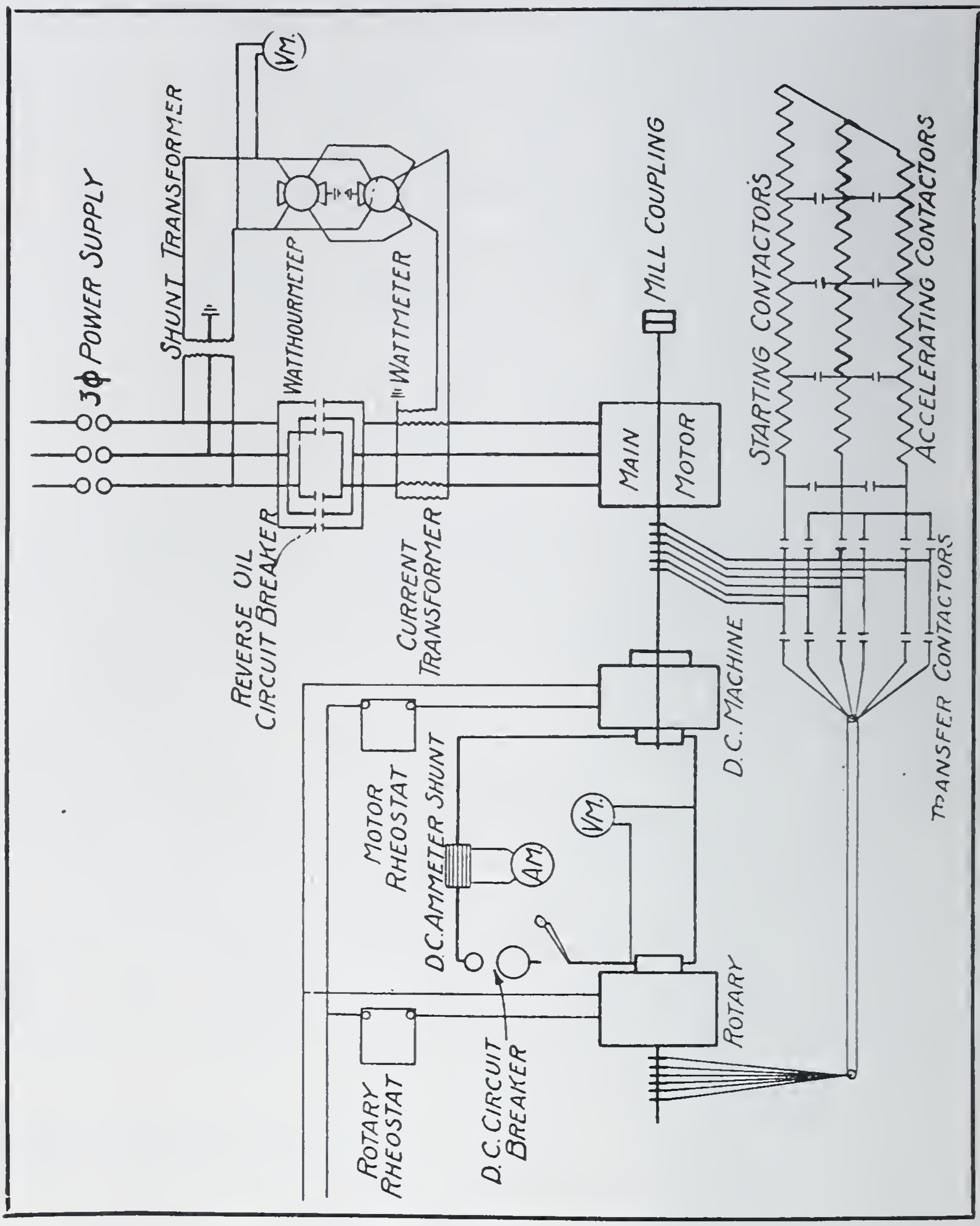


Fig. 3. Diagram Showing Connections for Constant and Variable Speeds.

Fig. 4 illustrates a 700-horse-power equipment installed at the Syracuse Crucible Steel plant on a 12-inch merchant mill. The direct-current motor can be seen in the foreground, coupled direct to the main alternating-current motor. The slip energy from the secondary of the main induction motor is returned to the shaft as mechanical energy through the rotary converter and the direct-current motor, thus increasing the torque as the mill is slowed down, producing constant horse-power at all speeds. The rotary converter and the control panel are installed separately in the

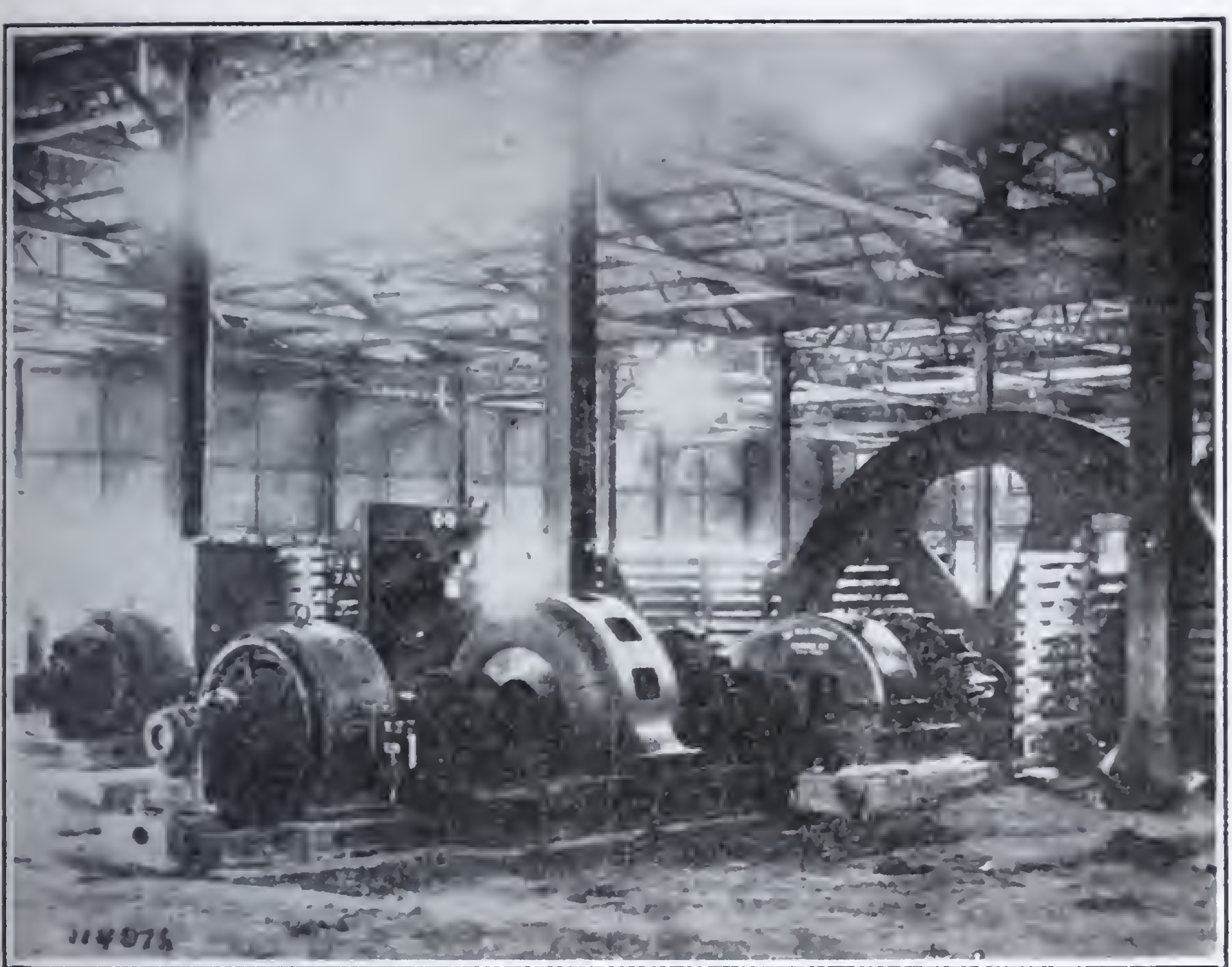


Fig. 4. A 700-Horse-Power Equipment on 12-Inch Merchant Mill.

rear. This particular set is connected to the mill through a gear reduction; a flexible coupling being used between the motor and the pinion shaft, and another flexible coupling between the gear shaft and fly-wheel shaft.

Fig. 5 is another illustration of one of these sets, this particular one being a 1500-horse-power, constant-horse-power, rotary-converter, adjustable-speed set, used in driving the 18-inch structural mill at the Saucon plant of the Bethlehem Steel Company. This set is direct connected to the mill, through a large fly-wheel, and operates through a speed range of 133 to 81 r.p.m.

The rotary-converter system permits a change in speed from time to time as the rolling schedule is modified, but like a direct-current, machine-tool motor, it is not intended to make rapid or extensive changes in speed under load conditions. If it is desired to have the motor respond to changes in speed during normal rolling conditions, it will be found better to install a direct-current

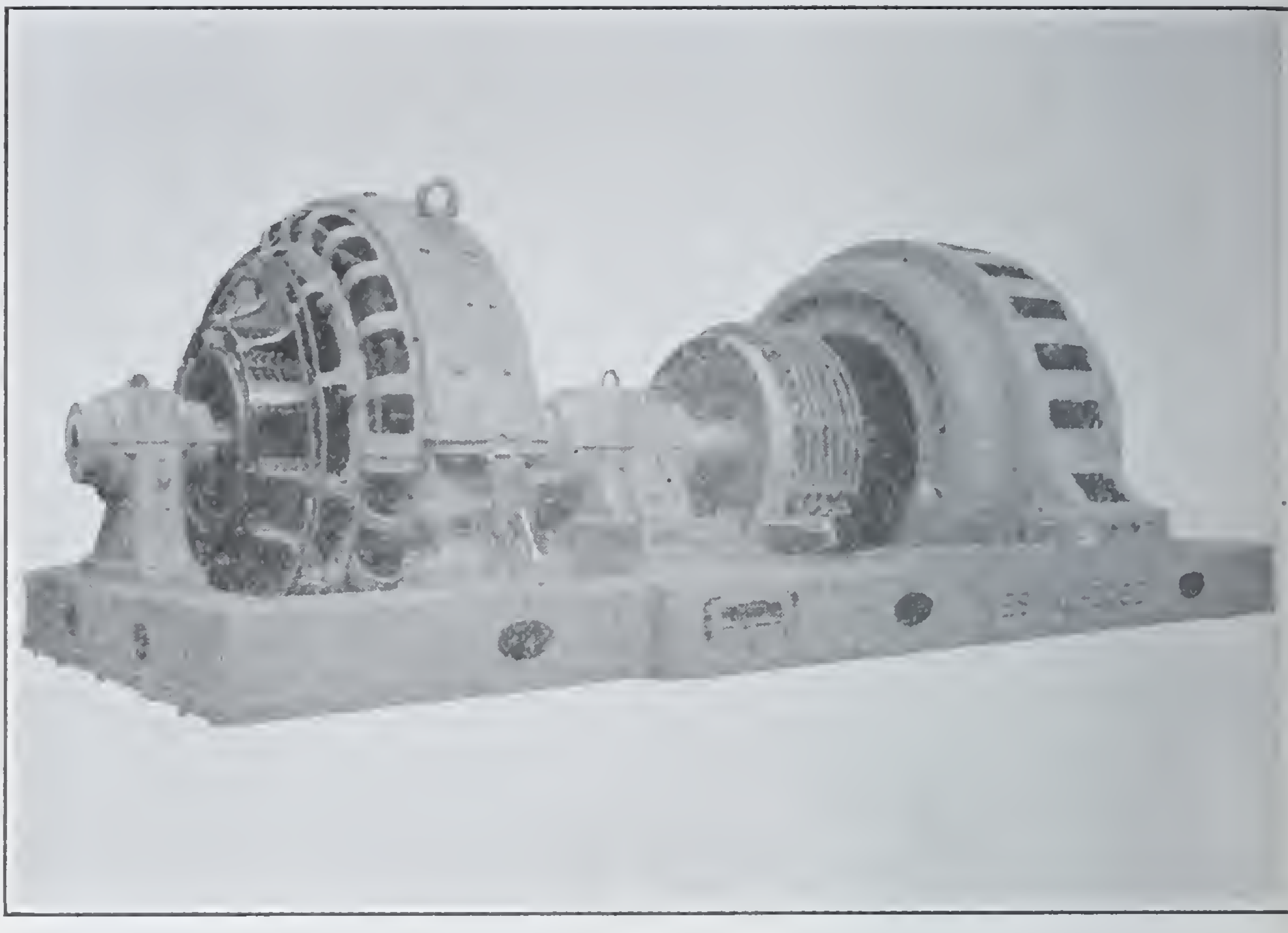


Fig. 5. A 1500-Horse-Power Equipment on 18-Inch Structural Mill.

motor on the mill, with a motor-generator set, and use the Ward-Leonard system of control. This system is similar to the ordinary reversing mill apparatus, except that the fly-wheel on the motor-generator set may be omitted on mills not having loads of a highly intermittent character.

An outline of this scheme is shown in Fig. 6, which represents a direct-current motor direct connected to a three-high, three-stand mill, supplied with power by the generator forming part of a fly-wheel set, the fly-wheel equalizing the input to the alternating-current induction motor driving the set. The Inland Steel Company has a drive of this type on a 28-inch, three-high, three-stand finishing structural mill, as shown in Fig. 7. From 12-inch to 24-inch beams are rolled and during the early passes it is necessary to slow the mill down to enter the metal in the rolls. After this, the mill can be speeded up to finish the long passes at a high rate of speed.

This is illustrated in Fig. 8, which is a graphic speed curve taken when rolling one beam at a time. The speed of each indi-

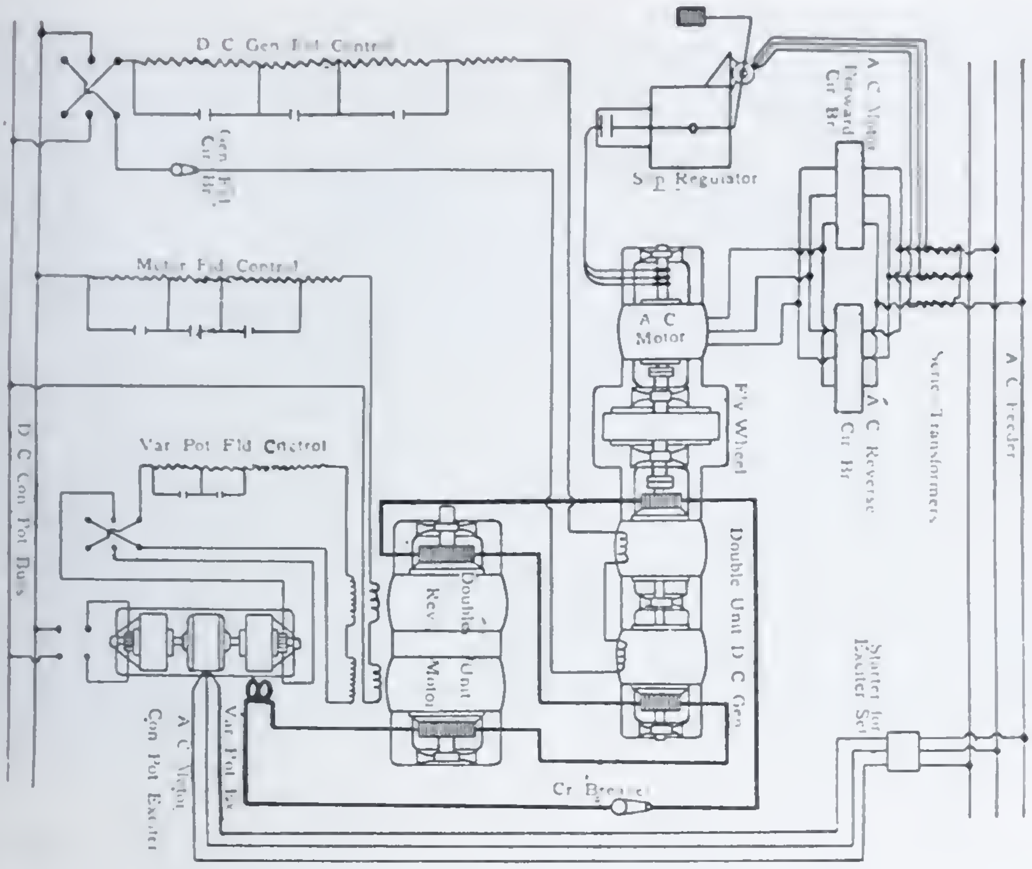


Fig. 6. Schematic Diagram of Connections for Double-Unit Reversing Mill Motor.

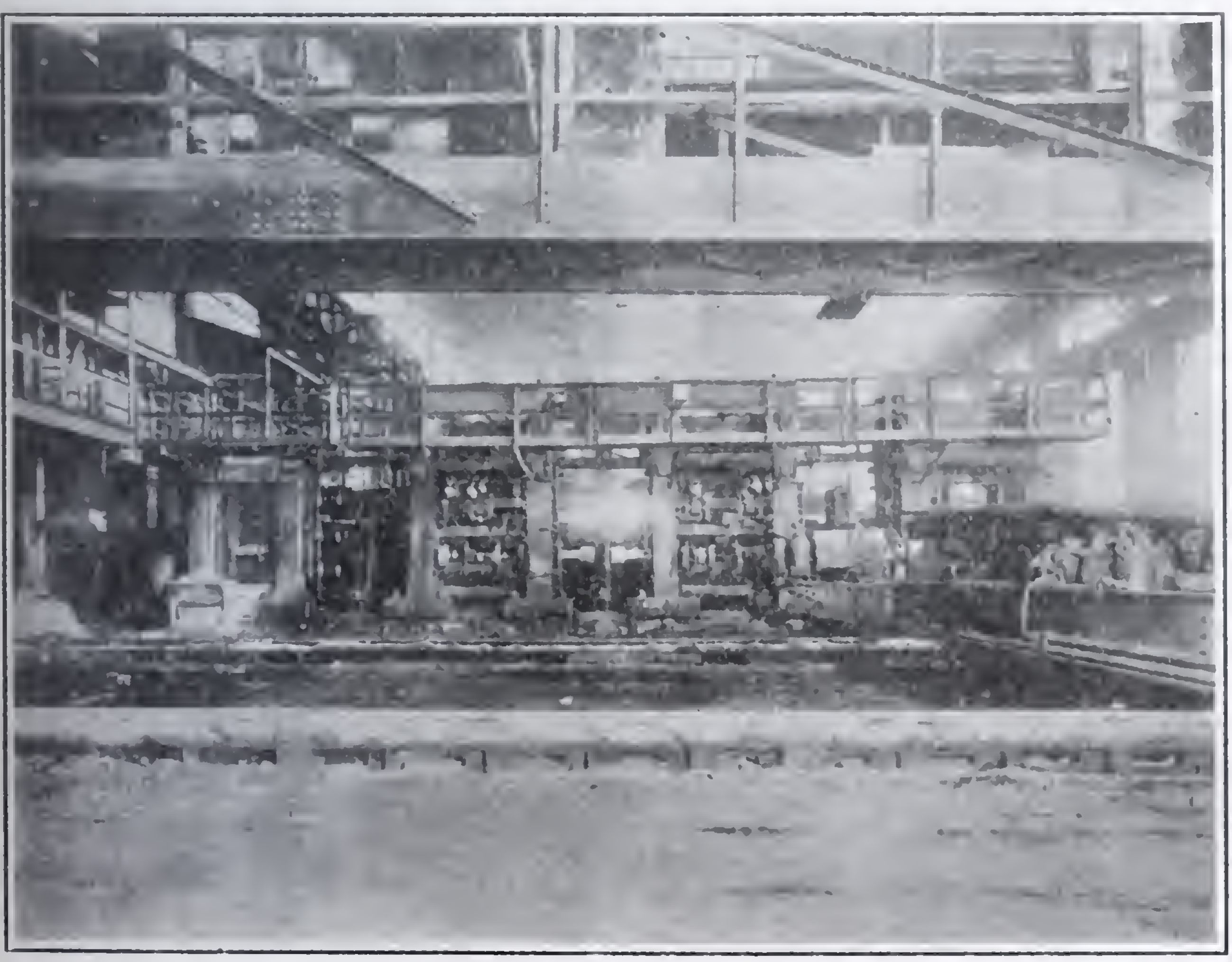


Fig. 7. Equipment on 28-Inch, Three-High, Three-Stand, Structural Mill.

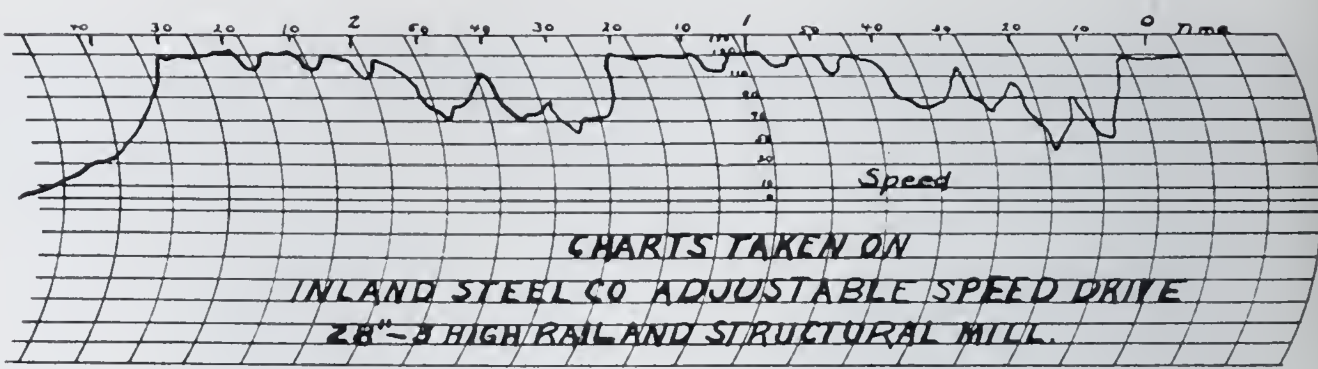


Fig. 8. Speed Curve Taken when Rolling Beams.

vidual pass is shown on two separate pieces and it is found that the speed is varied from 50 r.p.m. during the first passes to 125 during the latter passes. Under normal operating conditions, two pieces will be found in the mill at one time, which means that if the last pass is being made at the same time as the first or second pass, the mill will be slowed down at the instant the beam blank enters the mill and then immediately speeded up. This change in speed is obtained by merely manipulating the field of the generator and motor. A drive of this type is more important on a structural mill or a mill rolling steel of very irregular shape where the flanges cool off more rapidly than the web or body of the metal, since this difference in temperature makes it more difficult to produce the same flow of metal throughout the entire cross section. It can easily be understood that, having a drive which will finish the material with the greatest possible despatch, a more uniform product is insured. A motor equipment similar to this is being installed by the Algoma Steel Company on a similar mill which will be required to roll both rails and beams. This flexibility of speed variation simplifies the problems met in rolling such a wide variety of difficult shapes on the same mill. A motor of this type would also be suitable for a mill where at times it is desired to finish the tie-plate section shown in Fig. 2. The motor should be operated at the maximum allowable speed at all times in order to have the metal maintain its temperature as high as possible for the last pass. During this last pass, the mill would have to be slowed down in order to allow the metal to flow fully into the recesses in the rolls and the motor would need to have considerable power at these low speeds as compared to that required in rolling ordinary bar sections.

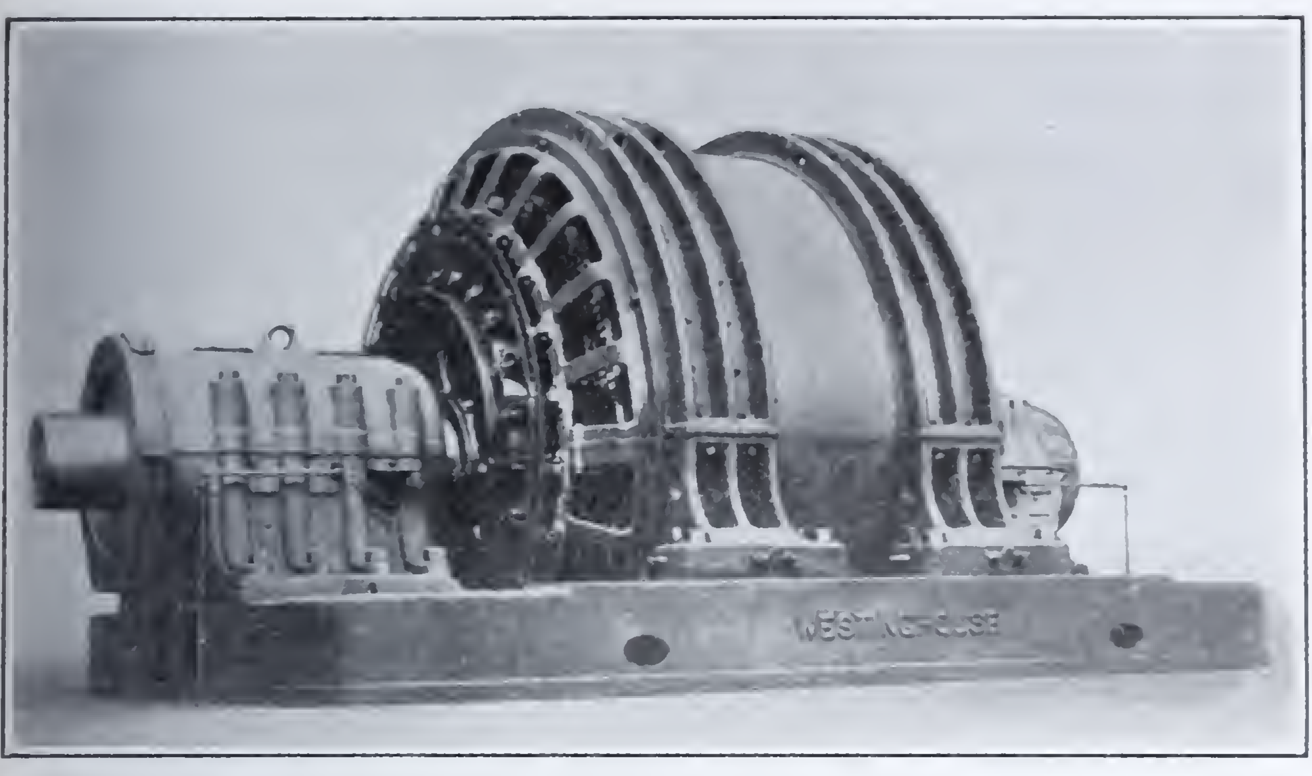


Fig. 9. Double-Unit, Reversing-Mill Motor.

Fig. 9 illustrates a double-unit reversing motor similar to that represented in the diagram shown in Fig. 6. Where two armatures are utilized on the same shaft, they are electrically connected in series to the two generators, similarly to the arrangement shown in Fig. 10. These generators are shown connected solidly to the fly-wheel shaft, and it in turn to the alternating-current induction motor. The latter takes alternating-current power from the generating station and is designed to carry the average load on the mill. The fly-wheel absorbs peaks above this average load when the passes are being made, and, during the interval between passes, the induction motor continues to operate at full capacity, bringing the fly-wheel up to speed for the next pass.

The two drives referred to on the three-high mills at the Inland Steel Company's plant and Algoma Steel Company's plant, are single-unit motors, each supplied with power from its single generator.

In order to avoid the deleterious effects on steel caused by improper temperatures for rolling, the mill should be arranged to dispose of the steel with despatch and avoid unnecessary losses in temperature. This is extremely important when rolling strip or plate, as thin material of this type cools off very rapidly, particularly during the finishing passes. In Fig. 11 are shown two

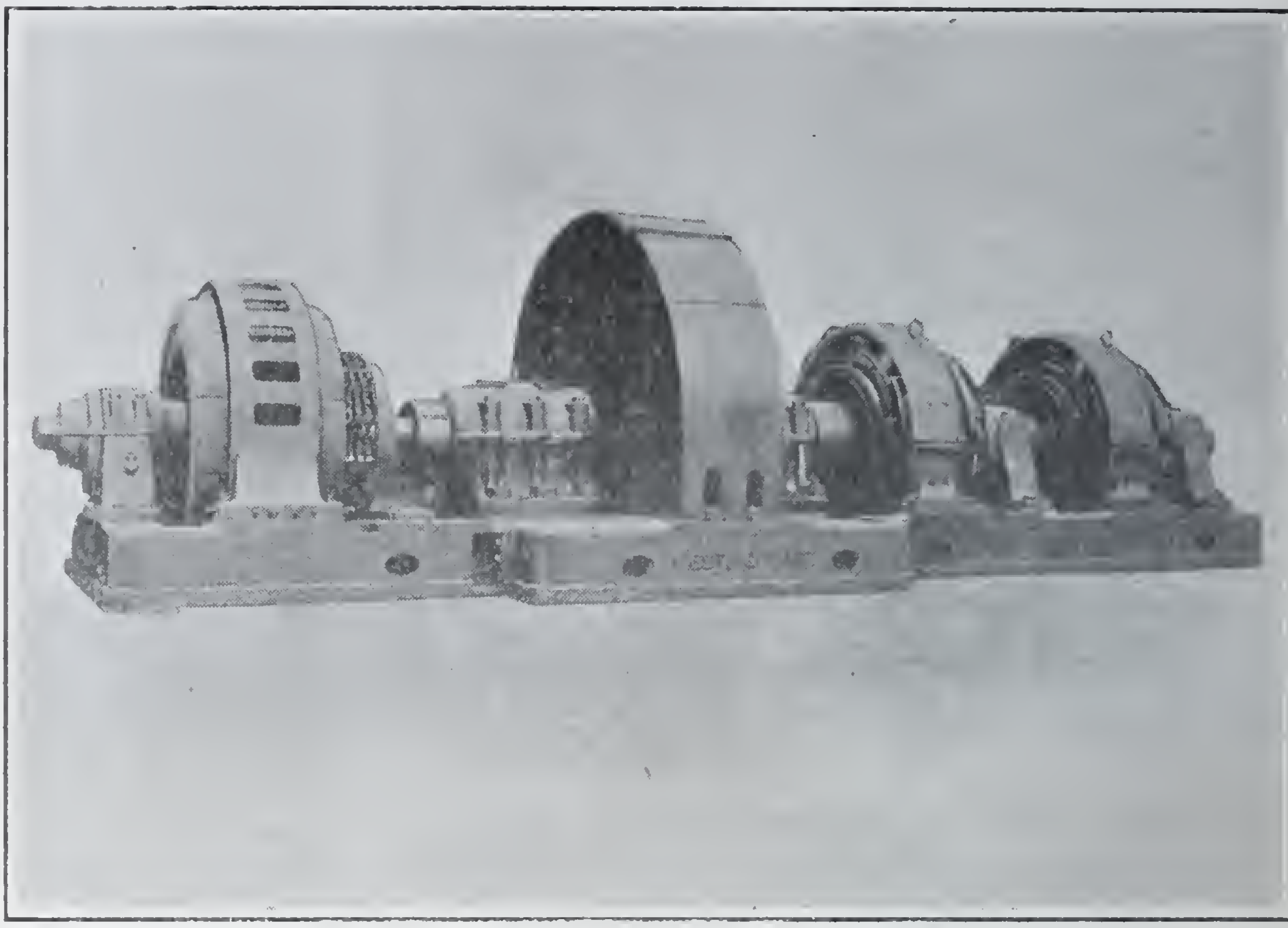


Fig. 10. Use of Two Armatures on the Same Shaft.

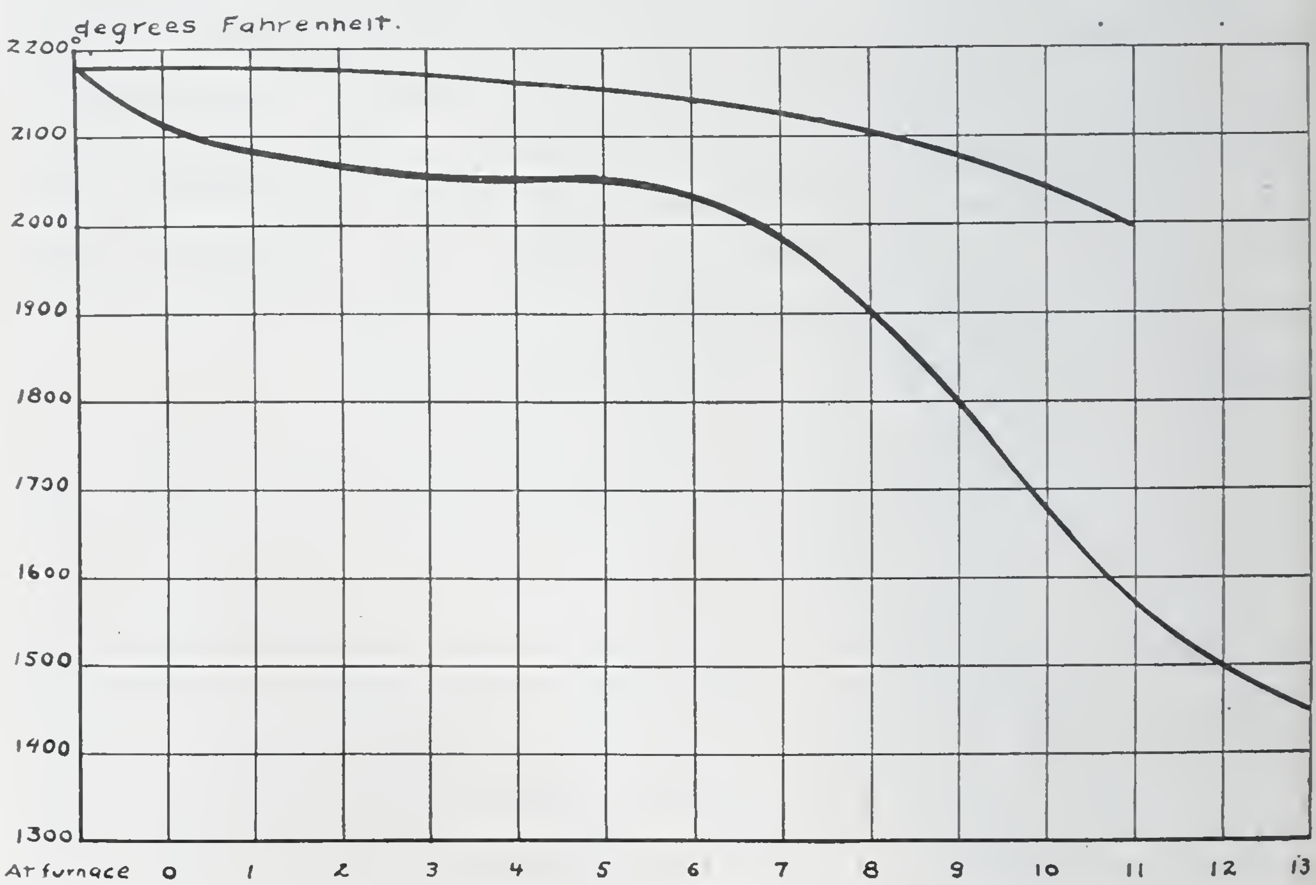


Fig. 11. Temperature Variation while Rolling Steel.

curves which graphically represent the temperature from the time the metal leaves the furnace until it is finished. It will be noted that the steel represented by the upper curve received a soaking heat and the temperature was to a large degree maintained by utilizing the shortest time possible in transferring the steel from the furnace to the mill, and then finishing it without any unnecessary delays; while the lower curve represents a steel which had been given a wash heat and then rolled on a mill where the arrangements to transfer the steel from the furnace to the mill were not the best. This resulted in cold steel which was hard to handle in the mill, all tending to increase the difficulties of producing satisfactory finished material.

An average of eight seconds was required to bring the steel from the furnace to the mill, represented by the upper curve, while that of the lower varied from 25 to 58 seconds. This delay permitted an accumulation of scale, which in turn introduced further delays due to the fact that the scale had to be brushed off before making the initial pass. When it is understood that the time interval from the furnace to the first pass is only eight seconds for the upper curve, and averages 34 for the lower curve, the large difference in temperature drop is easily understood. From the first to the sixth passes, the two curves are approximately parallel, but, beginning with the seventh pass, the fact that the steel represented by the lower curve did not receive a soaking heat is made quite apparent. The kilowatt-hour consumption per ton of steel produced under these two conditions was in the ratio of 2 to 1. Abnormal power consumption in rolling steel is not only unsatisfactory from the point of view of increased cost, but is a very good indication of the type of finished product being produced.

Previous to the installation of motors on rolling-mills, the size of engine and fly-wheel applied was largely based on the size and character of the mill, but, now that it has been possible to make elaborate tests on motor-driven mills, a much more detailed study is being made of the maximum efficiency possible in rolling. The method of manipulating the steel between passes is extremely important in determining the size of the driving equipment. This point is illustrated by referring to Fig. 12 and 14, the former

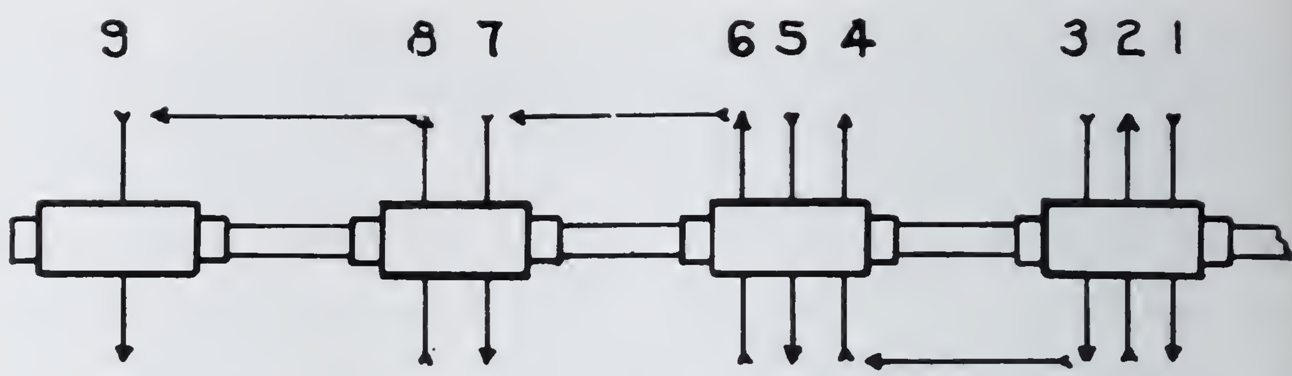


Fig. 12. Pass Arrangement of Three-High Stands with Traveling Tilting Tables.

representing a three-high, four-stand mill served by two pairs of traveling tables. This method of manipulation makes it possible to get two passes in the mill at one time, as is indicated in Fig. 13, which shows the resultant load on the mill. Fig. 14 represents the same mill where the steel is carried from one pass to another by means of inclined conveyors. This increases the tonnage possibilities, and mills of this type should receive very careful study. In this particular case, it is possible to get three passes in the

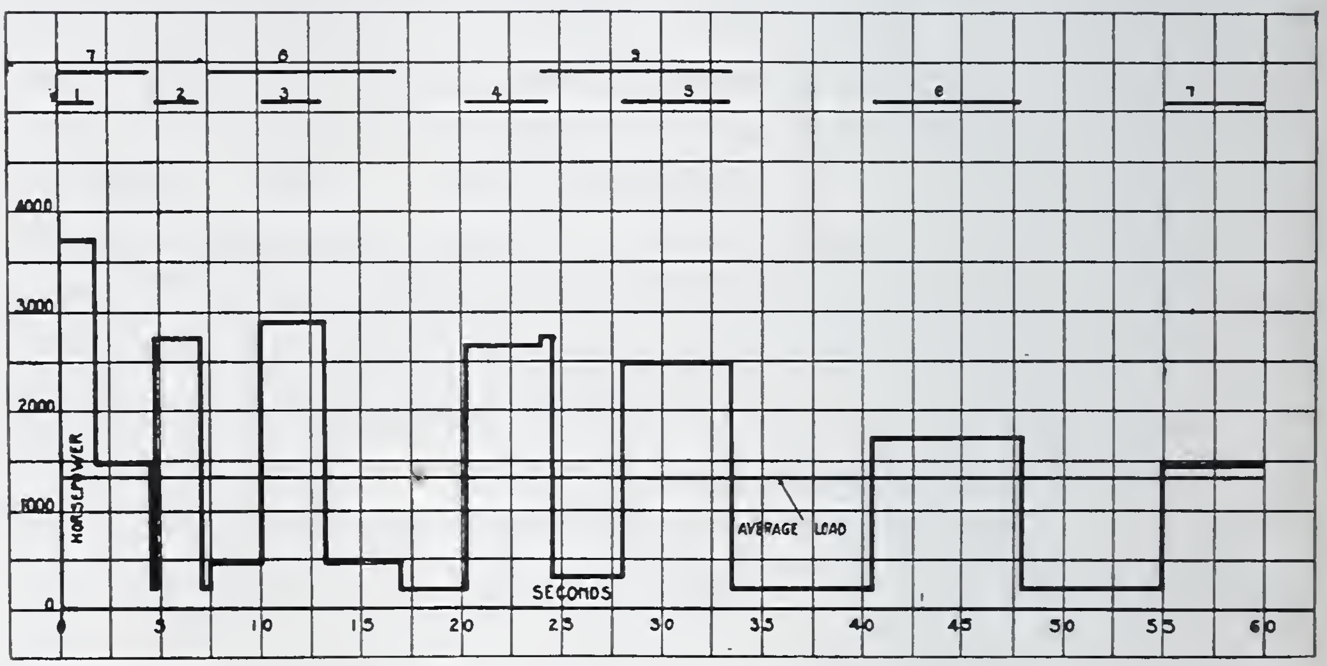


Fig. 13. Power Requirements of Mill Shown in Fig. 12.

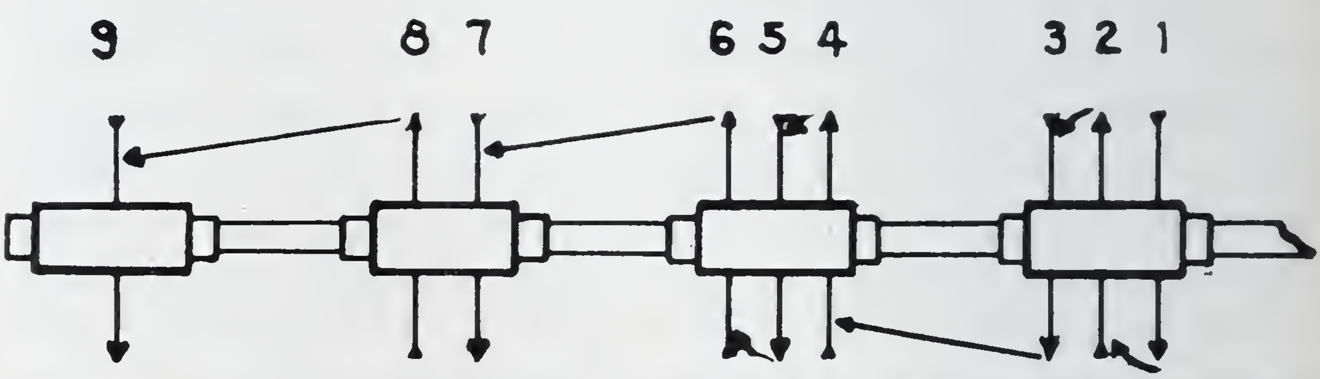


Fig. 14. Pass Arrangement of Three-High Stands with Inclined Conveyors.

mill at one time, the limiting feature being the manipulation of the steel between passes seven and eight in the third stand. A piece can be entered every 25 seconds instead of every 60 seconds, as is the case when traveling tables are used. The average load has been raised from 1325 to 2900 horse-power, as is shown in Fig. 15, but it will be noted from the peaks above these average

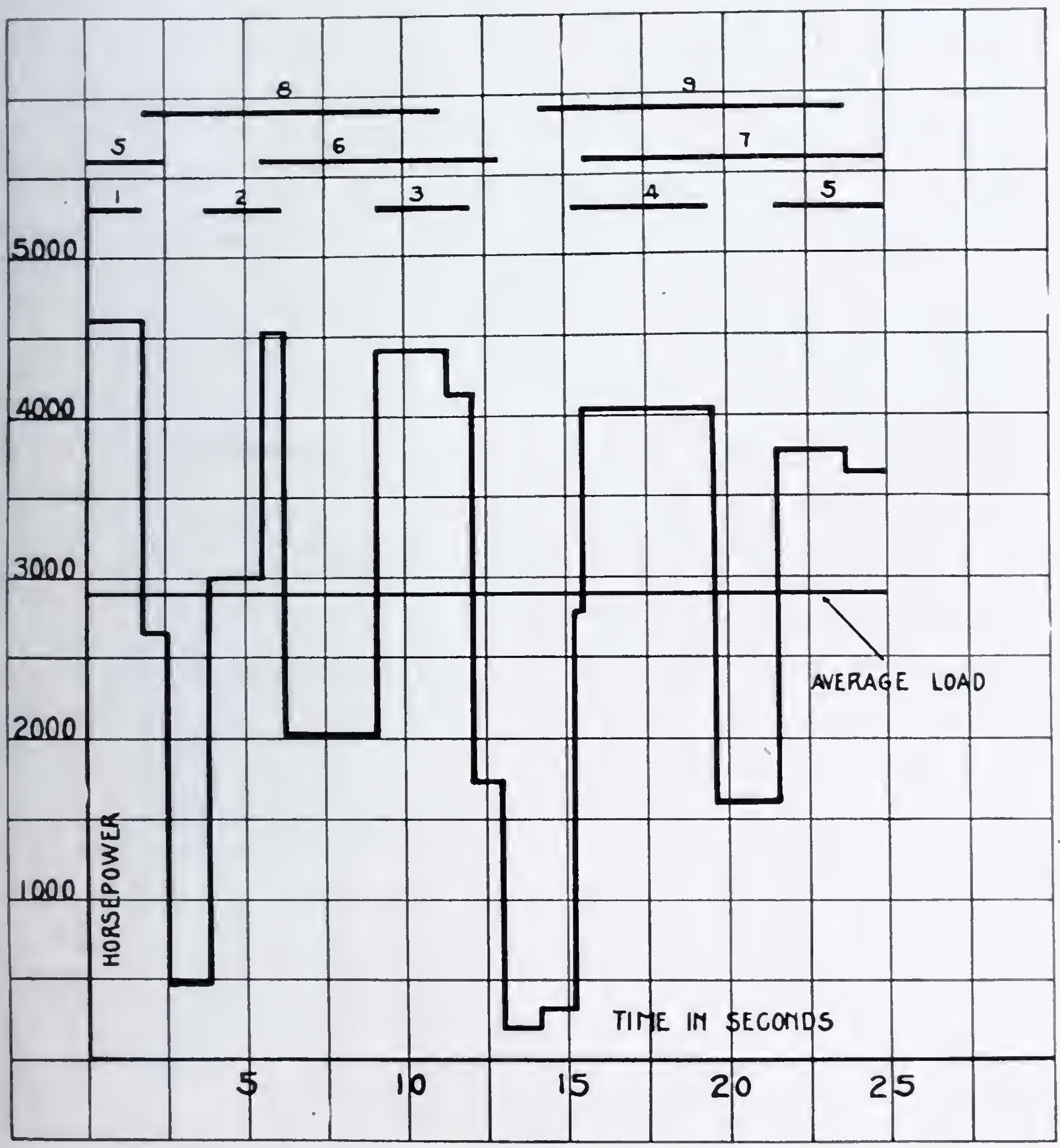


Fig. 15. Power Requirements of Mill Shown in Fig. 14.

loads that the fly-wheel effect has not been greatly changed. The actual power consumption per ton of steel produced would be somewhat less on the mill represented by Fig. 14 when rolling material of comparatively light cross-section, but not so different

when rolling heavy sections, particularly if the steel is properly heated and no great delay caused in bringing it to the mill.

Most of the mistakes which are made in selecting the proper size of motor and fly-wheel for mills, are due to a lack of proper analysis of the rolling conditions desired. If estimates are made on the schedule requiring the maximum power, it is possible to determine the motor and fly-wheel with greater accuracy than it is possible to maintain on the mill. It is, of course, understood that the mill or roll-neck friction while rolling steel varies considerably, and also the physical properties and temperature conditions of the steel change from day to day over ranges which are more or less difficult to control. Still, it is surprising how these variations cover the same range on various mills of the same nature. Recently the writer had occasion to measure the temperature rise obtained on the bearings of two 1000-kilowatt, motor-generator sets located in the same room and built at the same time and to the same specifications. The rise on one machine was 12 degrees C., while on the other it was 23 degrees C. This variation is beyond the control of the engineer who designed these machines, as the discrepancy is due to variation of shop manufacture. The condition of the bearing surface on the ordinary mill is crude as compared to that obtained on the standard motor-generator set, so that it must be recognized that variations in power required for rolling steel will, to a certain extent, continue; and we should not expect to obtain data which will enable determination of the power consumption beyond the limits of the variations just outlined. However, when extensive tests are made on several mills of the same character, and the normal range of the variations obtained is understood, a very accurate guide can be developed in the selection of the driving equipment if we have the heaviest rolling schedule available with sufficient data in regard to the method of manipulating the steel between passes, to know what intervals should be and can be used.

Forging, annealing and heat treatment of steel have received considerable attention and the results have added greatly to the quality of the finished product. While the subject of hot rolling may be less important, we believe it should, nevertheless, receive its proper share of attention.

We believe, therefore, that the installation of a mill should include proper heating furnaces and handling equipment as well as the general arrangement of the mill so as to be able to handle the metal with the necessary despatch to avoid unnecessary loss of temperature; and the driving equipment should be selected to handle the steel to the best advantage, keeping in mind the character of the product to be rolled and the temperature range within which it can be successfully worked. In the majority of cases, a single-speed motor can be used, but there are a number of places where it is possible to meet the proper rolling requirements only with a motor which can have its speed adjusted from time to time, or with one having the Ward-Leonard system of control, making it possible to adjust the speed instantly.

In addition to this, a study should be made to determine the maximum possible output of the mill and this should cover not only the mill proper, but should start at the furnace and be carried through the finishing department, so that the mill will be balanced throughout. If one or two rolling schedules are selected which require the maximum horse-power on the mill, a motor should be selected with sufficient margin to drive the mill when rolling under these extreme conditions. It is important to have a margin in the motor capacity so that it will not be disturbed when occasionally the temperature of the steel is not up to normal, or the passes are made under unfavorable conditions. If the motor gives trouble under these circumstances, the operating men very often blame it for any deficiencies in quantity or quality of the output rather than blaming the temperature, speed, reduction, etc.

A careful analysis, taking all of these conditions into consideration, should be made on mills where past practice is known to be good, bad, and indifferent; and if possible on experimental mills—such as proposed by Mr. Skinkle in a recent paper before this Society—which we are sure will bring out features that will upset precedents and lead to the adoption of ideas which will contribute to improvements over existing mills which might otherwise be duplicated.

DISCUSSION

Mr. O. Needham:* I think there is no doubt that in the future there will be more thought and study given to applying proper driving apparatus to rolling-mills than has been done in the past; and this study has been made very much easier since the general introduction of electric drive, because, as shown this evening, electric drive furnishes a very convenient and easy means of analyzing rolling conditions.

Most mistakes in applying apparatus, as Mr. Stoltz has stated, are due to lack of proper consideration of different factors that go to influence the rolling—factors such as different methods of manipulation, different arrangement of furnaces, etc. In mills that may otherwise be duplicates, the manner of handling the steel might differ considerably, which would materially affect results. In selecting a motor for a mill, it is practically essential that the future possibilities of the mill be carefully considered. We should look for the "neck of the bottle;" that is, ascertain what will be the final limit of the possible tonnage that can be rolled.

Sometimes on new mill installations, the furnace capacity may be smaller than the mill capacity; or, again, the cooling bed or shear may be the limiting feature and the tendency sometimes is to install a drive just large enough to take care of present conditions.

It often happens that after a mill is operated for a time it becomes desirable to increase the output, which is generally done by increasing the furnace capacity or shear capacity, or whatever happens to be the limiting feature. The result is that the drive may become overloaded.

It sometimes happens that the proper attention is not given to the subject of fly-wheels. I have in mind a mill of the cross-country type on which, due to the length of the different passes, it was thought no fly-wheel would be necessary. This mill consists of five finishing stands so arranged that no single piece of

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steel will reach from one stand to the next. However, due to the overlapping of passes in the different stands, some fairly high peaks are encountered. Fig. 16 and 17 will illustrate this point. Fig. 16 is a graphic wattmeter curve taken on this mill when passing one piece through the mill at a time. Fig. 17 is a graphic wattmeter curve on the same mill with billets following each other through the mill as rapidly as it will permit.

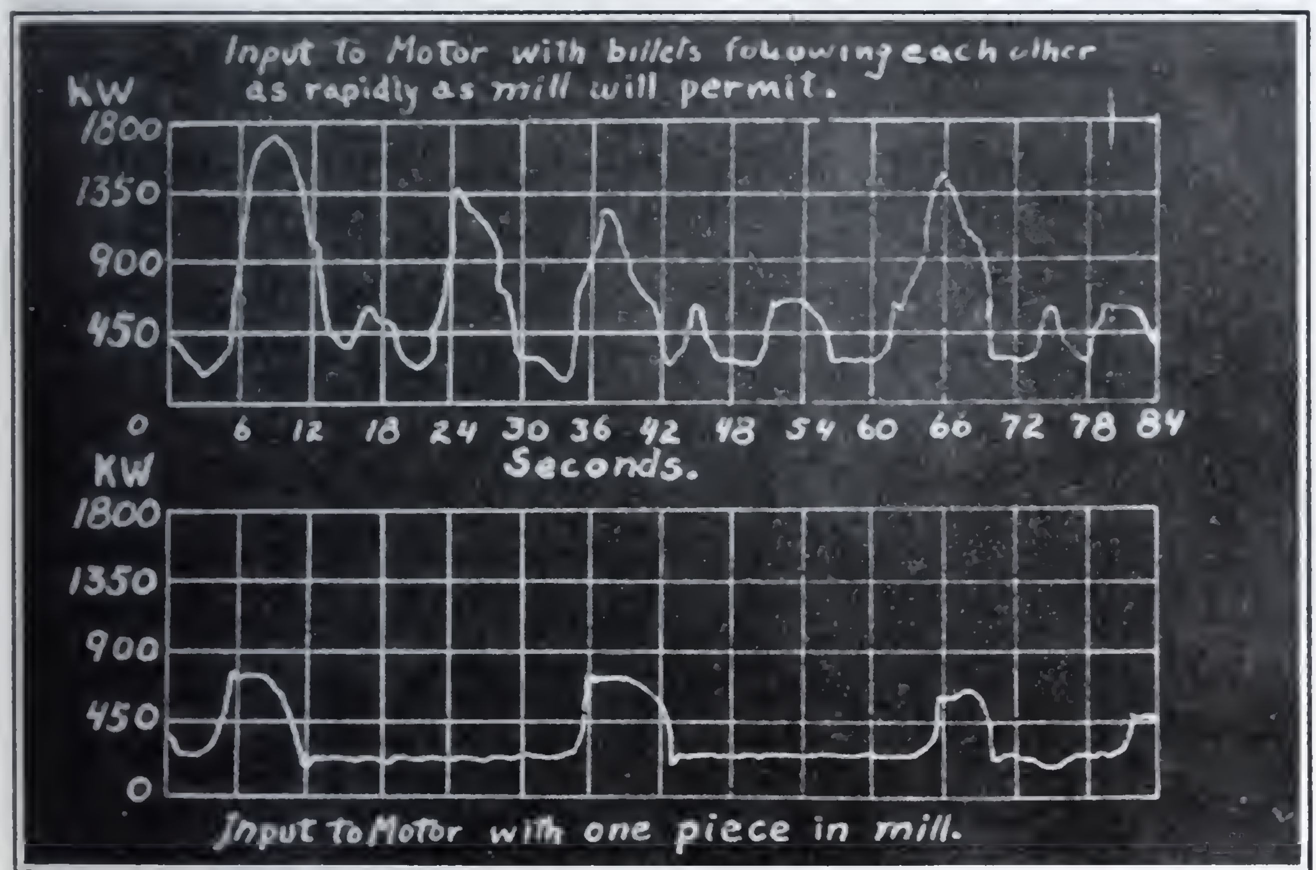

Fig. 16. Curves on Cross-Country Mill Showing Feasibility of Fly-Wheel to Eliminate Peaks Due to Partial Overlapping of Passes.

The curve in Fig. 16 was taken when rolling a comparatively light schedule. Fig. 17 shows a calculated curve on this same mill, rolling considerably heavier billets. It has been found on this mill that the peaks sometimes become so high for short periods that the motor will stall, and the advisability of installing a fly-wheel to assist the motor over these high peaks has been considered.

I have in mind another mill which has been in operation for a number of years in which a mistake was made in selecting the mill speed. This mill was intended for rolling alloy steel. After the mill was placed in operation, it was discovered that, due to the wide variety of sections required to be rolled, adjustable speed

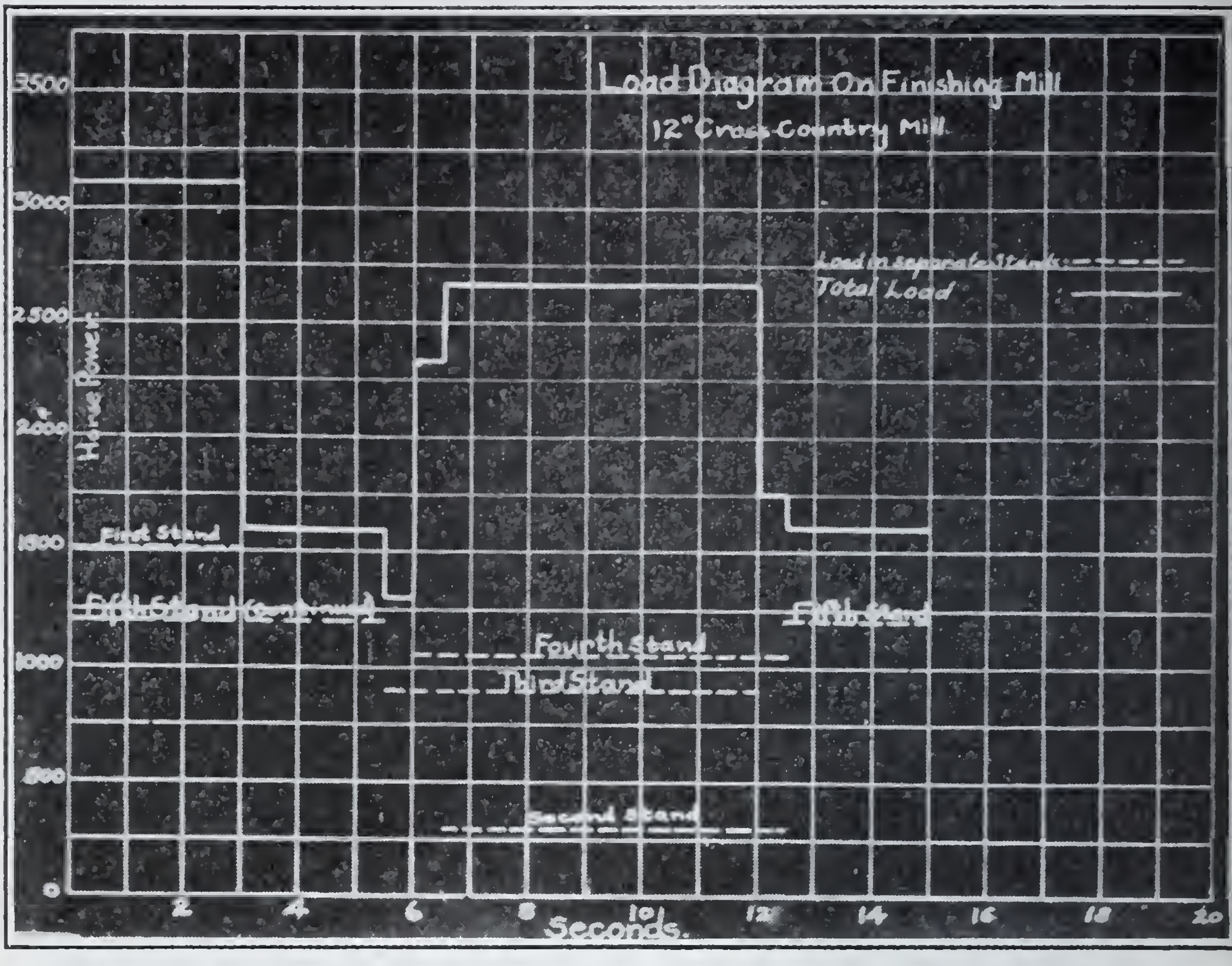

Fig. 17. Load Diagram on Finishing Mill.

was necessary and the auxiliaries required for making an alternating-current, adjustable-speed set of the motor, were added. This is one of the earlier installations of alternating-current, adjustable-speed drives in this country.

I have pointed out the above examples as being along the line of Mr. Stoltz's paper, showing that a careful study of mill conditions before the drive is finally decided upon may save considerable trouble and expense, later.

Prof. W. Trinks:* Mr. Stoltz was kind enough to send me an advance copy of his paper so that I have had the advantage of having had time to look it over. I think he has given us a very good paper and has shown that the Westinghouse Electric & Manufacturing Company builds a good alternating-current, adjustable-speed motor. It also, incidentally, shows what trouble the alternat-

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ing-current motor gets into. As long as we had the steam-engine, we never ran into that trouble; we simply put a heavier weight on the governor or changed the diameter of the pulley, and no fuss was made about it. But when we come to electric drive and find the speed to be wrong, with a direct-connected mill, we are in the soup unless we are careful enough not only to think beforehand, but also to think right. But modern sales methods to-day are such that the "forethought" very often comes afterward. Sales engineers come along and tell the prospective customer all about the solution of his problems. The customer feels that he does not need a consulting engineer and he buys on the salesman's advice only to find out that cheap advice is very expensive.

Coming to the paper itself, I wish to take one or two exceptions. First, to the statement Mr. Stoltz makes about the point where the metal becomes plastic and loses its elastic properties. I am one of those theoretical fellows who take exception to statements of that sort. Steel is always plastic, even when it is cold. Otherwise, all of us engineers would be in a terrible plight. As soon as we have local stresses in steel which go beyond the elastic limit, that steel would break if it were not plastic. And this plasticity helps out many an engineer who makes a mistake in his calculations. On the other hand, steel is elastic at rolling temperatures, although not very much. I believe what he should say is this: "at a point where the elasticity is so small as to be almost negligible and where the plasticity is so great as to be almost wholly present."

Then I take exception to the "natural rate of flow." I think there is no such thing as that. I do not know how many of you were present at the meeting at which I presented a paper a few months ago where I discussed the stress which is required to deform steel at varying temperatures and at varying rates of deformation. The rate of flow is simply a question of how much force we are willing to spend, how much torque we are willing to put into the motor. We can deform cold steel if we are willing to furnish the power and if we make the draft small enough to avoid tearing the steel. I think that, instead of "not to exceed the natural rate of flow," we should say "a rate of flow at which the stress is not excessive."

Speaking of the speed of a mill, there is one factor which Mr. Stoltz has omitted and which is very important, and that is the ability to handle the product. A man can take a 2 by 2 or a 1 by 1 bar coming out of a mill with considerable speed, and he can handle it. But if 6 by 6 material comes shooting out at him he can not handle it at the same speed as a 1 by 1 or a 2 by 2. If large material is to be handled by hand, we must run the mill at a considerably reduced speed.

Another point which was brought out is that steel is usually rolled more slowly when we have heavier sections and more rapidly with light sections. From the temperature conditions and the so-called natural rate of flow which Mr. Stoltz brought out, we should expect the reverse to be true. We would want to handle the large sections more rapidly because the steel is hotter, and the small ones more slowly because the steel is cooled off more. I think there are other conditions present. If we rolled large sections as fast as small ones, we would get into trouble on account of breakage. We seldom have the feed rollers and the mill running at the same speed and we would likely have a considerable breakage of rolls.

Another point is that if we should try to roll the heavy section as rapidly as the small section and take as much draft we would not have the power. Our peaks would be beyond the limit of the screen over there and beyond the limit of the page in the PROCEEDINGS.

I think we all ought to be thankful to the engineers that they have given us the alternating motors with adjustable speed. But I would like to see in the PROCEEDINGS some photographs of installations, not of the mill itself, but of the electrical equipment. When you look at these diagrams they look pretty complicated and are apt to scare the mill man away from using the equipment. I am sure the actual apparatus will not look nearly as complicated.

MR. W. B. SKINKLE:* I do not know that I can add anything to the discussion. If it could have had the support it had a right to expect, the experimental mill proposed in connection

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with the Carnegie Institute of Technology would have been able to give us a great deal of information on this subject. But the companies have not come forward to help and the Institute is not financially able to install the mill. I spent 13 months trying to collect $150,000 from the steel industry of the Northeast quarter of the United States. In that time I approached 236 companies and interested about 150 in investigating the matter. Then we formed a parmanent association, which did not involve the expenditure of any money, and that 150 shrank to about 30. Then, when we finally brought out definite contracts requiring the payment of a given amount of money to put in this installation and a small fee to maintain it, the 30 shrank to about 8, and out of that 8 only 5 were steel companies. Of course, I have lots of promises from a large number of companies to go into this thing, but we can not build mills on promises and we could not possibly get those people to sign up a final contract. As a result the Carnegie Institute of Technology has had to put this plan on the shelf for an indefinite length of time.

Mr. J. R. Buchanan:* The speaker of the evening has explained one system of adjusting the speed of induction motors —that is, the rotary-converter scheme. There are also other means of accomplishing this; for instance, by using a regulating motor, direct connected to an induction generator—thus forming a direct-connected, motor-generator set. This latter system permits double-range operation—that is, operation of the main motor above and below synchronism, which advantage is not possessed by the rotary-converter scheme.

There is an added advantage with this system which permits the use of a standard-design mill motor with three-phase secondary, standard automatic contactor control with provisions for current limit acceleration and emergency stop by reversing the master controller. The induction generator is a strictly standard, squirrel-cage motor. Both the main motor and the induction generator may be transferred and used elsewhere, if desirable, at some future time.

The double-range system permits the operation of the main

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motor non-regulating at an average speed, with maximum efficiency. Ordinarily, the average rolling speed is somewhere between maximum and minimum speeds, the maximum speed being used for light sections and the minimum speed for heavy sections, but the majority of sections are rolled between these limits.

In case of trouble with the regulating set, the main motor operating at an average speed will permit the rolling of a wider variety of sections with the single-range system. Furthermore, when operating at average speed, the regulating machine is disconnected and the system works at higher efficiency. Sections for which higher speeds are desirable can nearly always be rolled in an emergency at average speed with reduced tonnage, while if trouble develops with the single-range set, many low-speed sections cannot be rolled at synchronous speed.

Mr. G. E. Stoltz: Professor Trinks brought up the question of the difference between elasticity and plasticity. I believe there are two schools on that question, both of which recognize the same characteristics in the steel, the difference being mainly in their definition of these characteristics.

Another thing was the natural rate of flow. The thing with which I am impressed is that if we try to roll steel too fast cracks and snakes will be found in it. That is well illustrated where tool or certain alloy steels are rolled—if they are rolled slowly little trouble will result. Professor Trinks makes a difference between the peripheral and volumetric velocity of displacing steel. In discussing the natural rate of flow it is necessary to refer to the volumetric rate. He states that we can speed up if we reduce the draft, which is the same thing as limiting the volume of metal displaced in a given length of time.

We will be very glad to supply the photographs as suggested. I sent out another advance copy to a man who wanted a photograph of the mill. We will try to meet the wishes of both. Professor Trinks brought up a very good point—that the limitation in rolling steel is very often the ability to handle it on hand mills, and also the draft it is possible to take. There would be danger of breaking the mill if we attempted to make the first few passes the same speed that we can make the finishing passes, particularly

on a blooming mill. Probably the most important factor which limits the speed of the mill is the ability to have the metal enter the rolls. This is noticeable in a two-high blooming mill where the mill is slowed down when any difficulty arises in having the metal enter the mill. The first alternating-current, adjustable-speed set was brought out by such conditions. It was required to roll a variety of sections in a merchant mill, and it was found that the smaller sections could be rolled at the speed at which the mill was running, but it was impossible to get the material in the rolls in the larger sizes. In another case, we were trying to speed up a mill which had a flying shear that would shear the metal as it left the mill, and it was found that the shear was the limiting factor.

PROF. W. TRINKS: In further justification of what Mr Stoltz has said, the United Engineering and Foundry Company, a very reputable and well known firm, has issued a little booklet on merchant mills and has given a list of motors and the sizes commonly supplied. When your smaller concerns buy a motor, they invariably go to that booklet and select that same size motor. On investigating, we found that occasionally those motor sizes were right; but very often they were wrong, because the mill was not a mill of the type which the United Engineering and Foundry Company had in mind when they compiled that list. So you see lists of that sort, while very useful, must be taken with a grain of salt, especially by companies with a small engineering staff.

MR. G. E. STOLTZ: If we were to make a very careful investigation of various mills and list the size of motor that would go with certain mills, as the United Engineering and Foundry Company has done, without assuming that that size motor will be correct in every case, five years from now probably all those motors would be wrong. Changes in methods of rolling have changed the power requirements, sometimes doubling the load Records are going to be broken year after year. I have in mind a rod mill where the purchaser had in mind a 1200-horse-power motor. It was adequate at the time, but they found means of speeding up the mill; put in repeaters to keep the stands full the greater part of the time; used larger billets and heavier drafting; and the load on the motor kept increasing until to-day the motor

should be just double its size. Good practice to-day will be poor practice five years from now.

MR. F. M. VAN DEVENTER:*. Another question which bears on the point just made, arises in the motorizing of steam-engine-driven mills. I believe I have heard Mr. Stoltz, in another paper, explain that the rated horse-power of a motor which replaces an engine should be greater than the rated or indicated horse-power of the engine it is to replace. As this is an important point, I think it would be well to ask Mr. Stoltz to review the reasons for this difference.

MR. G. E. STOLTZ: In rolling-mills, we often recommend the use of a motor to replace an engine, and, as a rule, the motor has considerably more power than the engine. We are often asked to explain this discrepancy. One reason is that an engine slows down quite readily and in doing so increases its product, just as on a hill an automobile will decrease its speed to a point where the engine has sufficient torque to carry the car up the hill at a constant rate, if this is possible without shifting gears. With the steam-engine, the crew will notice this slowing down and keep the metal out of the rolls. It may appear that the rolling is satisfactory and producing all the tonnage that could be expected, but, nevertheless, the engine is limiting output. The motor does not slow down appreciably. Before it slows down to the same extent as an engine will, its breaker will open; and, as we commonly set the breaker at 100 per cent. overload, the operators will overload the motor to this extent and suddenly the breaker will go out leaving the metal in the rolls. This is similar to the question that was asked as to why it took two 40-horse-power motors to run a street car when formerly two mules would do it. The size of the motor should be such that the mill speed will not suffer when the mill is crowded to its fullest extent. In one instance it was necessary to put a speed indicator on a mill to demonstrate the fact that they needed a larger motor. Every slab that went into that mill would cause the speed to drop from 83 to 50 r.p.m. in six or seven of the heavier passes, and it was

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not unusual to drop down to 30. This, of course, is not good operation as 15 to 20 per cent. is the maximum speed drop even where a fly-wheel is used. Some of the speakers spoke of changes that have been made in the driving unit of mills and indicated that serious mistakes had been made. I believe many of these changes have been brought about by the progress that is taking place from year to year. Rolling practice has changed, and our standards for the driving unit have been raised, just as we expect more from the present day street-car motors in comparison with the mules which were formerly used.

MODERN CONCRETE ROAD CONSTRUCTION; MACHINERY AND METHODS

By George A. Sherron*

Since the advent of the concrete road, much has been written regarding the design and methods of construction to be employed, but the other factor, the choice of plant and equipment, has to a considerable degree, been overlooked. This latter item is the one that is greatest in importance in the eyes of the contractor, who, personally, is a very important factor to be considered in the construction of any road, especially one of concrete.

The proper choice of plant means everything to the contractor, and his success and fortune directly depend upon that choice. The line of demarcation between profit and loss, is often very narrow, and we all realize that the contractor cannot continue to operate on losses. He must, therefore, carefully study each job and view it from all angles. No two jobs are exactly alike in all details, and a change in any combination of conditions quite frequently means a change in some respects in the method adopted.

The type of plant selected must meet all conditions in an economical and satisfactory manner—economical, because the contractor is bidding in competition, and is in business to make money; and satisfactory, because the results of his efforts must meet with the approval of the highway engineer. The engineering world to-day, has no respect for the contractor who bids in a job, simply to get it, and whose only hope to "get by" on the price bid, is to make it up on extra work or by "trimming" the contract; so, if the contractor cannot make money as the result of his operations, there is really no sane reason for him to continue in business. In other words, the contractor, as I view him, is a business man, who is laboring in the engineering field—that field where "dreams are made to come true," to the great benefit of mankind.

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For the sake of convenience the work of constructing a concrete highway may be divided into four operations, carried out in the following plants:

1. The unloading plant and filling station.
2. The transportation plant.
3. The grading plant.
4. The mixing plant (including all subsequent operations).

Let us now consider item one, after assuming that all aggregates, cement and supplies will be delivered by rail. Cement will be received in bags in box-cars; or in bulk, in which case it will be shipped in open-top cars, and protected from the weather by canvas covers or tarpaulins. In the latter case, it would be economical to ship only to a large job where it would be unloaded by the plant used for unloading the aggregates. The aggregates will be unloaded by one of the following methods, depending in some instances upon the transportation plant selected.

The simplest method of unloading is by hand, the aggregates being shoveled out of the car and into wagons. This method requires labor, a rather scarce article to-day, and a sufficient number of teams to keep that labor at work continuously, in order that the greatest "man tonnage" possible may be obtained.

In spite of all efforts there will be a considerable amount of lost time, which will be reduced by the use of the car unloader—a steel box, that is hung on the side of the car, and into which the materials are shoveled. This acts in the capacity of a small, temporary storage bin when the wagons are not on hand to be loaded. Upon their arrival, the gates of the bin are opened and the contents deposited in the wagon without loss of time. The hand method requires much labor and, except on small jobs or in exceptional cases, would not be used.

Hopper cars may be unloaded by one of the several types of belt unloaders that are now on the market. They may discharge directly into the wagons or trucks, or upon the ground, to be later loaded into the wagon by shovels or another loader. In either case, some hand labor will be required.

If the topographical conditions are right, a trestle may be constructed, with bins underneath, into which the cars will dis-

charge their contents, and from which the trucks or wagons will receive their load. This method is very economical to operate, but the first cost is considerable, and can be supported only by a large job having the topographical conditions favorable for the correct trestle location.

The unloading may be accomplished by means of a derrick or crane. In either case a clam-shell bucket would be used. Derricks are of three types: the stiff-leg, movable stiff-leg, and guy. Given sufficient yard space, the area over which aggregates could be piled with the stiff-leg derrick would depend upon the length of the boom within the area of its swing. The movable type has a much more extended range. The efficiency of the guy derrick depends upon the length of the boom, as material can be deposited only in a circle around the mast. Where a crane is used it may be of either the locomotive or the auto type, and, in the latter case, it would either move on wheels or have caterpillar traction. The crane is the most elastic unloading unit, but it is also the most expensive. The area of deposition of material is limited only by the yard space and the number or extent of the railroad sidings available. The clam-shell buckets would have a capacity of from one to one and one-half cubic yards, if the material is unloaded into bins, and not to exceed three quarters of a yard if directly into trucks. Wherever possible, bins should be provided, as the aggregates can be drawn off from them in accurately measured amounts. Bins are absolutely essential where industrial railroad is used for transportation of aggregates, and these should have a capacity of not less than thirty batches. Where trucks are used, the bin capacity should be not less than five truck loads. All aggregates in excess of the bin capacity will be piled in stock piles on the ground adjacent to the bins, and as fast as these are emptied they will be refilled from the cars on the siding, and when no cars are present, from the stock piles.

From the above it will be noted that on the larger operations a crane or derrick would generally be used, and the aggregates unloaded from cars or stock piles to loading bins from which they would be loaded into small cars, batch boxes or motor-trucks. No attempt will be made to discuss the cost of these plants, other than to state that the larger the job, the more extensive the scale

of operations, and the larger the plant required. There are several modifications of the methods noted above, that I will not consider, except to call attention to the fact that unusual conditions frequently demand unusual methods, and these often result in exceptional and widely diversified types of plants, and a considerable number of failures.

The next thing to consider is the "transportation plant." All necessary supplies, cement, aggregates, etc., must be gotten to the job, at a minimum of expense and effort, and in such time and quantities, as not to delay the operation of the mixer. Before anything further can be done, the contractor must decide whether or not he will deposit the aggregates upon the subgrade. Sometimes this question is already decided for him by the specifications. If the aggregates are to be deposited on the subgrade, the simplest plant, but not always the most economical, is a string of horses and wagons. This method is applicable to the small job, where the hauls are short, and where the topographical conditions, such as grades and the condition of the roads over which the hauling must be done, are such as to prohibit the use of other methods. The next method would be the motor-truck, by means of which larger loads could be hauled, at greater speed, and at a lower cost per ton-mile. The method of depositing the aggregate upon the subgrade has the advantage that the hauling can be done when the roads are in condition to withstand it; and work can be carried on shortly after a rain, and before the roads have entirely dried up. The contractor can also see his aggregates at the mixer, and a glance tells him how long he can operate if the outside supply is shut off. It means a smaller investment in plant, but a larger investment in labor. In order to haul greater loads at one time motor-trucks with trailers may be employed, and the capacity may be increased by the use of the tractor with a long string of trailers. Industrial railroads have also been used to bring the material to the subgrade, in which case the cars would have V-shaped bodies.

Where the specifications prohibit, or where the contractor decides that he does not wish to deposit material upon the subgrade, the aggregates may be brought up by one of the following methods; motor-truck with batch boxes, trucks with subdivided

bodies, or industrial railroad with batch boxes. There were several instances during the past year where the first two methods were used with more or less success; but, on a regular job of any size, and where the topography permitted, the latter method has been more extensively used and with greater success.

This method of hauling material for concrete road constructions was introduced some years ago, the idea being to dump the batch of sand and stone directly from the cars into the charging skip of a side-loading mixer. This was not a success, however, as the track was not always at the same relative elevation as the mixer, and the mixer used was not large enough to permit the industrial railroad to be operated to full capacity. Cars of two-foot gage, manufactured by the industrial car manufacturers, are universally used. The track comes in 10-foot sections and is easily handled. The factors that affect its use are, grades; whether or not the line must pass through a town, or over streams not sufficiently bridged; and the usually large investment in the equipment. A fifty thousand dollar contract cannot support a forty thousand dollar plant, unless the contractor already has the plant on hand and no other or more important work for it. There is no doubt that industrial railroad haulage as applied to road work is a very satisfactory operation from an engineering standpoint. The subgrade can be prepared for a long distance ahead of the mixer, and if the specifications provide that a subgrade templet be used, the operation can be carried on much more satisfactorily, and the subgrade shaved to a true surface. From the information given, it will be readily seen that each job, especially in the eastern section of the country, presents its own particular problem, which must be solved successfully by the contractor assisted by the engineer.

Where the industrial system is used, the railroad plant should be located with extreme care, every effort being made to reduce the average haul as much as the railroad location will permit. The minimum equipment for any job, would be two locomotives and three trains of not less than 15 cars each. Each car would carry two batch boxes, each of which would contain one batch or charge for the mixer. That would provide material at the mixer for one hour's operation where a mixing time of 1.5 minutes is

specified. One or more sidings will be necessary at the filling station, and one will be located at the mixer. This is generally placed two day's work from the mixer and at the end of the second day, it is moved to an advanced position. The motive power may be steam or gasoline and the engine may vary from three tons upward. Where gasoline power is used, the locomotives are of two types—friction driven and gear driven.

Batch boxes may be made either of wood or of steel. The steel box is neater and lighter than the wooden box, but after it has been in a wreck and battered up, it cannot be repaired as easily as the wooden box. The cost is about the same for either kind. There are three types of boxes—the tip over, the side dump, and the bottom dump. The bottom dump seems to find greater favor with the contractor, as it can be discharged with greater ease and less spilling of its contents. The tip over type kicks back as it is discharged, and quite frequently some of its contents is not deposited in the charging skip of the mixer. The side dump necessitates a false bottom placed at an angle, in order that the material will slide out; and, therefore, requires a larger and heavier box for the same capacity. The choice here rests entirely with the contractor. On large jobs this work is under the direction of a superintendent of transportation and trains are operated on schedule. A telephone installation aids in the despatching of trains.

Where the motor truck with batch boxes or with subdivided body is used, the aggregates are kept off the subgrade, but, as is frequently the case after a rain, the ground may be soft, and the subgrade is sometimes badly cut up. Then, too, the roads leading to the work may be in bad condition and the trucks delayed. The batch boxes are transferred from the industrial cars and motor-trucks by a power-operated derrick on the mixer, or by a road crane operating from the grade. The truck must remain idle at the mixer until all of the boxes have been unloaded. Where the subdivided body is used, the regular dump body on the truck is divided into compartments by means of partitions, and each compartment will carry one batch for the mixer.

Upon arrival at the job, the truck is backed to the charging of the mixer and elevated. The tail-board is then released and the first batch slides into the skip. The remaining batches are dis-

charged as needed, by releasing the partitions. One objection to this method is that each truck is tied up at the mixing plant while the successive batches are run through the machine, and if several trucks are operated as on a long haul, this would represent a considerable loss at the end of each day. A contractor should study this method carefully before adopting it. He should remember that the continued operation of his job depends upon the arrival, on time, of the trucks with the aggregates; if these are delayed due to break-downs of trucks or crane, poor roads, or any other unforeseen causes, the mixing plant can not operate as there is no reserve stock available at that end of the work. With the industrial railroad, delay may be caused by shut-down of the unloading crane or by a wreck on the line. With this method, a few cars with batch boxes filled with aggregates may be kept on the track near the mixing plant, to be used only in emergency. With the aggregate handled by the subgrade method, no such factors causing delay need be considered.

Let us now consider the grading plant. The method and equipment employed on this work depend upon the character and amount of grading to be done, the equipment available, and the amount of money the contractors wish to invest in equipment. Nearly all road contractors own rollers and most of them have handled grading jobs at one time or other. Those contractors would be sure to have rooter plows, drag scrapers, wheel scrapers, or fresno scrapers on hand; and for ordinary operations this equipment with the addition of a scarifier and road machine would suffice. If a contractor were outfitting for highway work especially, he would purchase a roller with scarifier attachment; or what is known as a maintenance roller.

The simplest and cheapest plant for this work is a rooter plow drawn by horses or a road roller. This is slow and laborious and would be used only on small jobs and where the grading was very light. On the average jobs, a road roller and scarifier or scarifier attachment would be used. This method when used under the proper conditions, is very satisfactory. On large jobs where the cut is fairly heavy, a turbine grader would be used. This machine will excavate and load from 60 to 90 cubic yards of material per hour depending upon the character of the material; and the

depth of cut can be varied from 1 to 24 inches, the cutting width being 5.5 feet. The advantage of this plant lies in the fact that one man operates it and that no labor is required for loading the excavated material into wagons or trucks. For very heavy grading, a steam-shovel would be necessary. On all work except where the turbine graders and steam-shovels are used, the excess material would be collected and removed by drag or wheel scrapers, fresno scrapers or road machines.

Fine grading, or the removal of the last two inches above grade, may be accomplished by hand labor with picks and shovels, by road machines, or by means of a machine known as a subgrader. This machine could be described as a gang scraper mounted and operating on wheels on top of the forms. When drawn along by a roller, it scrapes off the subgrade to finished grade and piles the material in two longitudinal rows that are easily removed from the grade by shovels.

Forms may be of wood or steel. The latter are preferable, as, with ordinary care, they are practically indestructible. Wood warps and twists, is rough, and hard to keep clean, and is much more expensive when service and durability are considered. There are several makes of steel forms and each type finds favor with certain contractors. The features to look for in a steel form are weight and stability, speed in setting and removing, and the bearing on the subgrade.

The mixing plant is a very important part of any road operation, as upon the continuous operation of the mixer depends the progress of the work; the contractor, therefore, should give considerable attention to this part of his plant.

Until a few years ago, concrete paving mixers of any size or capacity up to one cubic yard capacity (dry batch) could be secured. The sizes and capacities, however, were finally standardized by the Mixer Manufacturers' Association, and the present sizes obtainable are 10E, 14E, 21E, and 28E, the figures representing the wet-batch capacity of the machine in cubic feet. The popular sizes for ordinary contracts are the 10E and 14E, but, with the advent of specifications calling for 1.25 to 1.5 minutes mixing time, it becomes necessary for a contractor, especially on a large contract, to secure a machine that will have the greatest

output possible in that time. The size of his unloading plant and filling station, as well as his transportation plant, must be ample to meet the requirements of the larger mixer, and while the above may be taken into consideration, another factor must not be overlooked—the source of supply of aggregates and cement must also be sufficient to meet the requirements for maximum capacity of the plant selected. A failure in any of the above mentioned factors, means that the extra capacity of the mixing plant and its value in dollars and cents are wasted.

The contractor has already decided on the type and size of the mixer that he will use. This decision was made when he decided on the type and method of transportation, and to a lesser extent when the unloading plant was designed. If the aggregates are to be deposited on the subgrade, he will have to use wheelbarrows or some mechanical equipment to transfer them from the subgrade to the charging skip. The former method is the simpler but not the most efficient. With the "mixer loader," labor is saved and the output increased. The average laborer to-day will not push a wheelbarrow; and, as a result, on a job where they are used, one finds that the poorest workers are handling the barrows and they set the pace for the job. When mechanical equipment such as a "mixer loader" is used for this work, the machine sets the pace and the poorer workman must keep up his end, or the other men will see that he does. Then too, experience has shown that it is impossible to work the average mixer to capacity when barrows are used to transfer aggregate.

If, as previously noted, no aggregates are to be deposited on the subgrade, motor-trucks or industrial railroad will be used. If the trucks have subdivided bodies, no additional equipment for the paving mixer will be necessary. If batch boxes are to be used, the mixer must be equipped with a power-operated derrick, or else a crane must be provided on the grade for transferring the batch boxes. The derrick on the mixer is the least expensive and is most generally used.

All paving mixers, with the exception of those referred to as the 28E, have their own traction and may be moved at will. The power may be steam or gasoline and the traction may be on wheels or by the caterpillar system. The paving mixer should

have a power-operated charging skip and an automatic water-measuring tank and in the larger sizes it should have a power-operated discharge. Such a machine should be so designed that all operations save that of operating the power hoist can be controlled by one man. There are two methods of distributing the mixed concrete to the subgrade—the boom and bucket, and the chute. The former is the generally accepted method; but the chute is permitted if the construction is such that the angle that it makes with the horizontal is 20 degrees or more. On most pavers, a chute so placed would be about 12 feet in length, which would necessitate moving the machine at least every 10 feet. The boom is 20 feet in length, and moves with a machine thus equipped are made every 18 feet. The boom and bucket system handles the dry-mix concrete very well and there is no separation of aggregates. Manufacturers, as a rule, will equip with chute, or boom and bucket, as desired.

Mixers come in various designs, and some are built to wear while others are built to wear out. The drums are of iron or steel, or with steel body and semi-steel cast heads. In shape, they may be cylindrical, cylindrical with curved ends, cubical, or with each half shaped like the frustum of a cone, and with these halves fastened together at the bases. Mixers may be driven by gear or chain drive and the gear drive may be single or double. From a pratical as well as a mechanical standpoint, the double gear drive is very efficient. In this case the gearing is cast integral with the drum heads and one is stepped or set one-half pitch ahead of the other, giving a constant application of power. All paving mixers accomplish their mixing by the aid of blades and buckets in the machine. These vary greatly in number and arrangement, and it might be added that the average contractor when purchasing a mixer, would do well to pay more attention to the drum, mixing action, and discharge. This and the general design and construction are more important than price, especially as the contractor makes an investment when he purchases a mixer, crane, or truck, and he should see that he invests his money where it will bring the greatest returns in work.

The concrete, after distribution to the subgrade, is leveled, shaped and usually tamped. These operations may be performed

by hand or by machine. If by hand, the leveling and tamping will be accomplished by means of a strike board or tamper, of wood or steel, that is drawn along at right angles to the road and at the same time raised and lowered a few inches vertically. The concrete is then usually rolled about three times with a metal roller 8 to 10 inches in diameter and five to six feet in length. This eliminates all bubbles and air pockets. A smooth surface is imparted by the use of the finishing belt. This belt is rubber or canvas about 10 inches wide, and is drawn back and forth across the road and works out all small inequalities in the concrete. This entire operation may also be accomplished by means of a finishing machine that operates on the forms under its own power, and performs the operations described under hand finishing.

In conclusion, the attention of the reader is called to the fact that no effort has been made to single out any one type of plant as being more successful than another; but rather to bring out the different types of plant that would be used under the various conditions that are encountered in the field. In other words, the paper is a record or summary of the types of plant and equipment in general use to-day, as viewed through the eyes of the contractor.

DISCUSSION

Mr. J. P. Leaf:* I am certainly very much pleased to hear the contractor's side of the improved road problem. I believe the contractor's interests are similar to the engineer's. These improvements in making concrete roads by machinery are something that is very much needed, and I believe the future will justify further development. We may differ as to whether concrete, brick, or asphalt is the best road, but they are all good. It looks as though the concrete road had the lead just at present on account of utility and price.

I believe in the contractors and manufacturers paying attention to the mix, to the quality of the cement, and to producing a good road. I would like to suggest a point that I think should be taken into consideration by all road builders and road users, and that is, the foolishness of permitting 10-, 12-, and 15-ton trucks to go over our highways. At first glance it looks all right to build roads to carry any truck that wants to come down the pike; but the truck man owns the truck and somebody else builds and maintains the road. One heavy truck in a rain can put a road out absolutely for the farmer, automobilist, tourist, and everybody else going over it. As an engineer who has made a study of roads and built a considerable number of them, I believe that anything over 10 tons ought to run on steel as a railroad, and the truck owner might just as well say he has a right to go and run over the rails of the Pennsylvania Railroad as to come down in Beaver County and travel over our highways and beat them to death. There are miles and miles of good macadam roads suitable for as high as eight or nine tons, which should not be beaten to death by heavy trucks going over them at a high rate of speed. If heavy trucks must go over the road, they should be made to go over it at a low speed. When horse-drawn vehicles were used, a certain width of tire for a certain tonnage had to be observed and you had to drive below a certain rate of speed under certain

*City Engineer, Beaver Falls, Pa.

conditions, but, now, they do not say anything about how wide the tire should be or the rate of speed. There is no known material to build a road that will take a 10-ton truck at 15 miles an hour.

Mr. George A. Sherron: Your statement is borne out by the wear produced by the 10-ton government trucks coming east from Chicago. They broke up wood, asphalt, brick, and concrete, impartially. The State of Georgia taxes trucks of over 10 tons about $1100 per year. The State of Maryland also taxes them heavily.

Mr. Edward K. Brogan:* I did not notice that they used any reinforcing material on those roads. I am at present engaged in building a road using 2 by 2 angles on sides, and reinforcement of the American Steel & Wire Company's No. 32, using for roadbed a cinder fill rolled by a 12-ton roller.

Mr. George A. Sherron: They do not use reinforcement in Maryland or Delaware or further south. In this state, considerable study has been made of that and it has been definitely decided that reinforcement is absolutely necessary. In New York state, reinforcement is used more or less, and also in Massachusetts. In Connecticut it is used at times and at others it is not. In Rhode Island, Mr. Patterson, the Chief Engineer, is in a quandary right now. He has not decided whether to dispense with reinforcement or to continue the use of it. In the Middle West it is used by some states and not by others. I am not myself expressing any opinion for or against reinforcement, as that is a problem for the engineer.

Mr. J. P. Leaf: About expansion joints, what is the custom?

Mr. George A. Sherron: An excellent joint is that known as the Pennsylvania joint, which was designed by the Pennsylvania State Highway Department and prepared by Robertson Brothers in this city; the old two-layer, two-ply tar paper; the wooden joint; and the tar-paper submerged joint from an inch

*Contractor, Pittsburgh.

to an inch and a half below the surface, are all different types now being used. I recently examined some concrete road in Georgia where submerged joints of two thicknesses of two-ply tar-paper were used, and, in instances where the joints were not put in at right angles to the road, the frost action during the winter was such as to cause the pavement to raise up, and one slab rode over the other in some cases as high as four inches and spoiled, in possibly twenty places, over ten miles of road that was otherwise in very good condition.

Mr. J. P. Leaf: Is experience coming to the point of doing away with expansion joints very largely?

Mr. George A. Sherron: Yes sir. California does not specify them; nor does Delaware except at the end of the day's work, and in that case simply dowel joints in order to keep the road from getting out of alignment.

Mr. Israel R. Burt:* Aren't the conditions of temperature in California so much different from the conditions in Pennsylvania that it would not be safe to take California work as an example?

Mr. George A. Sherron: Surely.

Mr. J. P. Leaf: Whatever may have been the experience elsewhere, I think our Pennsylvania conditions call for expansion joints.

Mr. George A. Sherron: I think so. I was not expressing an opinion for or against.

Mr. L. P. Blum:† Without wishing to appear to criticize so excellent a paper, I confess to a little disappointment that more attention was not paid to the matter of expansion joints. The proper making of expansion joints in a concrete pavement has

*Department Superintendent, National Tube Co., Ellwood City, Pa.

†Blum, Weldin & Co., Pittsburgh.

very much to do with the life of a road. Whatever the material of the expansion joint may be, it is absolutely necessary that the slabs on both sides of the joint shall be at exactly the same elevation. A difference of 0.25 inch or even 0.125 inch will have much to do with the life of the pavement, by tending to produce undulation of the surface which will extend from the expansion joint to the center of the slab and thence to the next expansion joint. That is true, not only of the tar-bound pavement, but also in a lesser degree of the concrete pavement. I have seen some very ingenious schemes used to prevent this result. Perhaps the speaker, who is dealing in concrete machines, can tell more of this at this time.

Mr. George A. Sherron: I think I mentioned most of the joints. In California they tried out various types and my experience in California dates back to 1913. In the state highways in southern California practically no joints were used. We discovered during an especially hot spell in June, 1917, in the Imperial Valley section, that in intervals of two or three miles the expansion was so great that slabs would blow to pieces, portions of the road twenty to thirty feet long being affected. We had a couple of instances where machines were very close to the blow up. At that time the concrete roads in Los Angeles County were similarly affected. In this county they have over 3000 miles of paved roads. The county engineer and I went over the situation and we figured that if a bituminous joint about 8 or 10 inches wide were placed at the end of every mile, or even every half mile, it would take care of that excessive expansion.

In Delaware, the joint situation was studied very carefully on the Dupont Road and the engineer, Mr. Charles M. Upham, has very accurate charts that show the results in that portion of the road built with joints and the part built without them; and he has fewer cracks in that portion of the road built without joints. That is in sandy soil. Pittsburgh conditions are very different.

Regarding the reinforcement, I would give no decision one way or the other. In California they have used redwood strips one inch below the pavement at the shoulder. In some instances these were placed at an angle of 30 degrees which was supposed

to be the proper thing to do. Joints have been more or less defective throughout the history of the concrete road.

Mr. Israel R. Burt: The paper of the evening has been well presented and it is very evident that Mr. Sherron has given a great deal of thought and study to his subject. It has been entertaining as well as instructive. The discussion on expansion joints interests me very much. On the project with which I am connected, we are paving city streets with concrete; that is, we are building concrete roads. We are placing expansion joints, from 40 to 60 feet apart. The joint is of a regular manufactured material designed for expansion joints, and it extends from the subgrade to the surface of the concrete. We do not use a tool to round the corner next to the joint. Streets that we finished in this manner last summer are in a very satisfactory condition now, having developed practically no cracks. I would like to get an expression from others present, as to whether they consider this good practice, or if the joints could be placed further apart, with success.

Mr. Edward K. Brogan: I would rather use them at 30 feet. I am putting in expansion joints every 33 feet to suit my reinforced cuts, using a corner tool on expansion joints for hardening purposes. The corner tool is special, as it penetrates the joint one inch, with a slight radius.

Mr. J. P. Leaf: There are two things I believe worth while observing in concrete road construction. One is that a great deal of this expansion is due to using cement that is too fresh. We all write our specifications calling for fresh cement, but there is no doubt that cement that has stood for two or three or even six months is better than fresh cement, and will produce much less cracking and expansion. The other is that we have been lax in putting in concrete that is not mixed enough. Cement mixed two minutes always makes a great deal better concrete than that mixed one minute or less. It is simply giving it that much more treatment. It seems to be worth while to get the sand and cement together in close union.

In expansion joints I have found this: The men in working the concrete into the joint will always work the stone ahead and the cement and sand will never get into it. To make an expansion joint you should use neat cement of half-and-half mixture right along the joint. Then, when these stones go in there a little bit of tamping will make the joint the strongest place in the road instead of the weakest. There are many places in the concrete that are perfectly solid stone, but around the edges and joints especially, there are many places that are just cement in the top and the rest is loose, on account of having the stone ahead and no means for the mortar to get in.

Mr. L. P. Blum: Mr. Sherron, have you found a two-handed roller any better for finishing concrete roads than a single-handed roller?

Mr. George A. Sherron: Personally, I like a single-handed roller. This can be equipped with a rope on each side, or with two handles. It is pretty difficult to handle a roller with a handle on each side, especially where any trees grow up fairly close to the road.

Mr. L. P. Blum: Isn't is apt to produce a more uniform cross-section.

Mr. George A. Sherron: I could not really say about it being better.

Mr. Israel R. Burt: On our work we use two ropes on the roller, one on either side. This, of course, requires two men for operating, but it has the advantage of not requiring so much open space at the side of the road in which to operate.

Mr. L. P. Blum: The paper of the evening is a first-class illustration of the modern tendency to substitute machinery for human labor. Such substitution is in the interest of both the engineer and the contractor. In my opinion, the amount of public and private work that will be done in the immediate future

will depend upon the extent to which such substitution can be effected; it is, therefore, in the interest of the engineer and the contractor to get together to substitute the machine for human labor whenever it is possible to do so.

This development, it seems to me, places upon the engineer an added responsibility. The speaker has properly touched upon the wrong done to the public, at times, by the acceptance of the lowest bid received from a contractor insufficiently equipped to perform the work. Most engineers know from experience how difficult it is to persuade public authorities to reject the low bid. The public can see nothing but the comparison of the figures of the two bidders; they can see nothing of the fact that one bidder is fully equipped to perform the work while the other is more or less incompetent to do it; that with one bidder it is a matter of doing the job efficiently and in a few months, while with the other it may be a matter of delay over several years, to the consequent inconvenience and damage to the public during the construction period. I know of a case recently where the lowest bid had been accepted from a man whom every one connected with public life in Western Pennsylvania knew to be thoroughly incompetent and unreliable. The work, which should have been done within one year, dragged over three years. The road to-day is still closed to traffic, the contractor having forfeited his bond. The public authorities took the bond and the amount of ten per cent. withheld, and relet the remaining work to another contractor; and even then the public authorities found that they had suffered a considerable financial loss. The acceptance of a bid a few thousand dollars higher than the lowest bid would have put the work into the hands of a competent contractor equipped with the proper plant; would have saved the public money, and given the public the use of an improved road for three years.

The engineer ought to be brave enough to prepare specifications in such a manner as to develop the facts as to the facilities of the various bidders to perform the contract; and he should make a frank comparison of equipment for the benefit of his client.

We have witnessed a very interesting and instructive illustration of modern machinery for grading; and yet there seems to be a field of grading that is apparently not covered by machinery;

that is, the grading of a new road on a side hill with a slope of say four to one. We are trying to make a cheap narrow road. By what we used to call side casting we excavate the uphill half of the cross-section and throw the earth down hill; thus producing a section of half cut and half fill. We used to get that work done for 25 cents a cubic yard. I received bids on the same sort of work the other day that ran nearly $2 a cubic yard. Where is the machine that will do that sort of work? The contractor says you cannot use a road scraper on it, the cross-section slope of the natural ground being too steep. What is your solution for that? The men who have perfected the turbine grader are certainly big enough to solve a problem like that.

MR. H. G. FARMER:* I am going to take exception to Mr. Leaf's remark that possibly the use of fresh cement will not produce as good a quality of concrete for use in concrete roads as cement that has aged for from two to six months; because (1) we know of no engineering data which will substantiate this statement; and (2) we can conceive of a possible condition when exactly the reverse would be true.

The physical and chemical properties of cement are affected only by the addition of or contact with water—or moisture from the air which is the same thing—and absorption of carbon dioxid (CO_2). The last named is a very slow process; consequently, its effect on cement is practically nil. Cement may be stored for a long period of time without affecting its quality, provided it is stored under proper conditions which tend to eliminate the possibility of intake of moisture. However, if the conditions of storage are such as to result in the cement taking up excessive moisture, the finer particles of the cement will become hydrated and will harden, and if this condition exists over a period of say six months, such cement will produce a concrete which will harden slowly and one that is very apt to be of inferior quality. We know of cases where cement has been stored for years without affecting its quality. We also know of instances where a few months storage under improper conditions has resulted in ex-

*Eastern Manager, Service Bureau, Universal Portland Cement Co., Pittsburgh.

cessive hydration of the cement, appreciably reducing its cementing value.

The point we wish to make is that the age of a cement is no criterion as to its quality. Satisfactory concrete can be secured by using either freshly ground cement or cement of considerable age provided the latter has been stored under proper conditions. Cement is but one of the several materials of which concrete is composed and is the only one manufactured under supervision. The quality of concrete is dependent upon many factors, including the quality of the aggregate used, the consistency of the mix, time of mixing, the manner in which the concrete is placed, and the method of curing. The proper curing of concrete is of great importance in concrete road construction.

There seems to be considerable interest in regard to spacing of joints in concrete roads. It may be of interest to know that the present specifications of the Pennsylvania State Highway Department require joints at intervals of not less than 200 feet nor more than 500 feet. Of course, a joint is formed at the end of each day's work. The old specifications of the Pennsylvania State Highway Department, now obsolete, required joints at intervals of approximately 40 feet.

SMALL STEAM TURBINES

By W. J. A. London*

The steam turbine field embraces prime movers from 5 horse-power capacity to 75,000 kilowatt. This range may be divided into three groups each one having its own fundamental basis of design controlled by commercial requirements.

a. Large main units of say 1000 kilowatt capacity and upwards.

b. Intermediate sizes say 300 horse-power or kilowatt to 1500, condensing, mixed pressure, bleeder, or non-condensing.

c. Small machines of 5 to 300 horse-power for auxiliaries and isolated plants, practically all of which operate non-condensing.

Class b embraces such a variety of designs, to suit the great diversity of requirements, that no hard and fast rule can be laid down to cover this class.

The machines in classes a and c are so clearly defined regarding the basic principles to be followed in their design that a definite comparison is permissible, and too much stress cannot be laid on the necessity of differentiating between these two classes of machines. What may be good practice in the larger machines may not by any means be a good example to follow in the smaller units and vice versa.

In the design of these two classes, the following major factors are considered and are listed below in the order of their importance:

Large machines	Small machines
a	c
1. Reliability†	1. Reliability
2. Efficiency	2. Simplicity
3. Cost	3. Cost
	4. Efficiency

*Engineer, Steam Motors Co., Springfield, Mass.

†In this class item 2, Efficiency, is often given preference to item 1, Reliability.

As this paper will deal exclusively with the designs of machines covered by class c, for the reasons mentioned above, any arguments set forth may not be at all applicable to the machines covered by class a or class b. It should be further stated that unless otherwise specified the single-stage, non-condensing machine is referred to exclusively when making general comparisons.

Referring to the relative importance of the items set forth in the second column, there can be little argument as to the correctness of items 1 and 2. Exception may be taken, however, to the order of 3 and 4. There are cases where efficiency must be carefully considered, but, in general, the order as given will be found to be substantially correct; not, perhaps, because cost is considered with the efficiency, but because the efficiency is not considered at all. A consideration of items 1 and 2 (reliability and simplicity) leads into a study of mechanical design which will be discussed in detail, later.

Returning to the question of efficiency of small turbines, the following maxims should be borne in mind by all purchasing engineers:

1. With a given wheel diameter and a given speed (operating conditions being the same), the steam consumption of any make of small turbine is substantially the same.

2. With a given wheel diameter, a given speed, and the same type of turbine, the actual steam consumption will be practically identical irrespective of the maker.

The above facts are accounted for because first, the laws governing jet and blade angles, friction losses, etc., are so generally known by all turbine builders that practically the same coefficients are used throughout; and, secondly, all small turbines are now manufactured in quantities. The manufacturer cannot put through special machines where stringent steam consumption guarantees are to be met (as in government work, etc.), and if one machine out of a series can be relied upon to meet this guaranteee it is reasonable to suppose that the efficiency of the others built at the same time and in the same lot cannot vary very materially from the tested machine.

While the question of true efficiency in auxiliary turbines is being better understood every day, the writer ventures the statement that there is still a need for a more analytical study of actual heat balance in the average station.

Considering the situation broadly:

1. If all the exhaust can be used, as in an open heater, the water rate is of little moment. (See Fig. 1.)
2. If the exhaust cannot be reclaimed, a turbine should not be used except in installations where circumstances preclude the operation of more efficient apparatus.

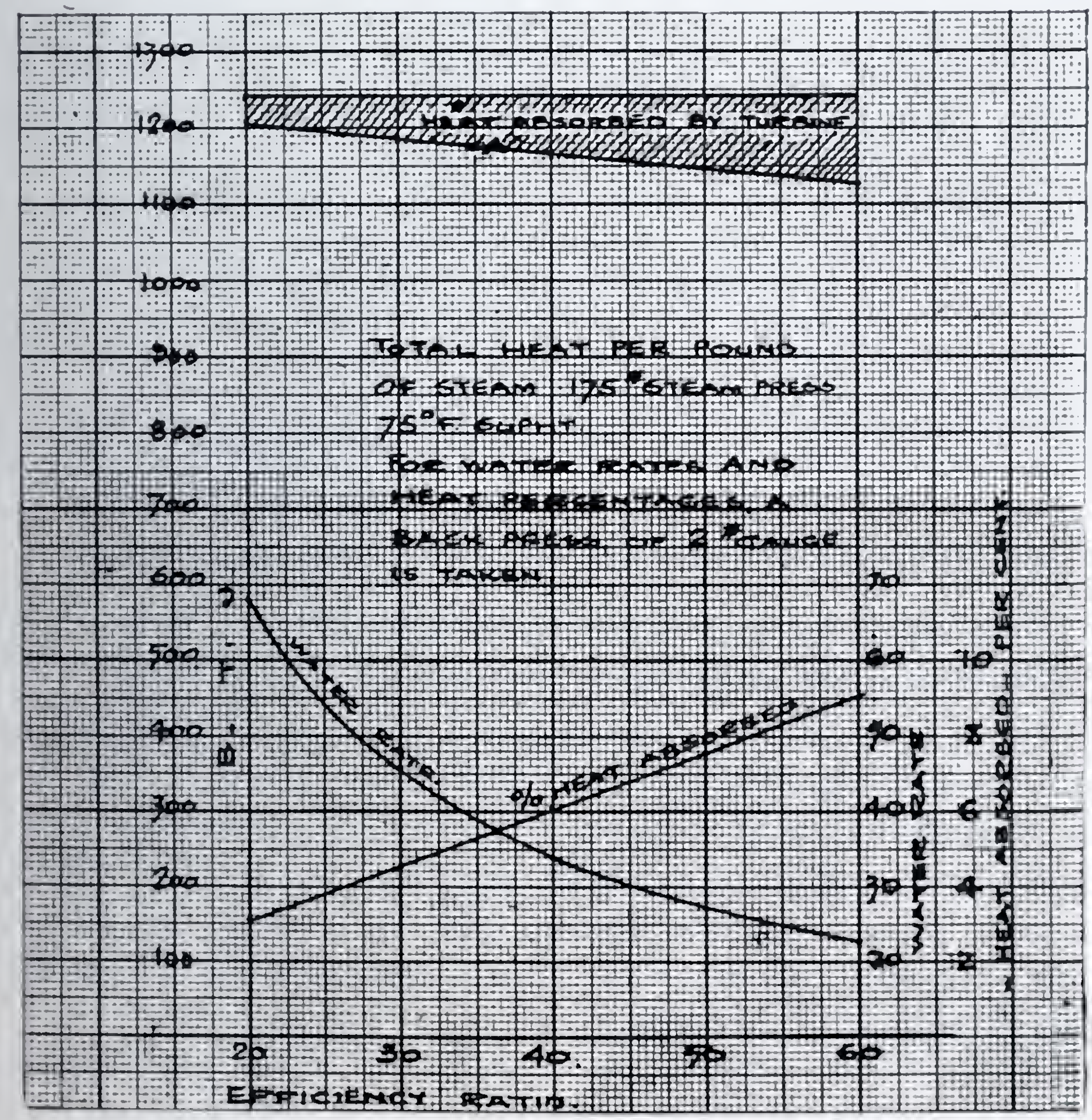

Fig. 1. Diagram Showing Amount of Heat Extracted from One Pound of Steam with Varying Efficiency Ratios.

3. If the exhaust requirements are variable, turbines should be used in places where reliability is paramount, and up to the point where *all* of the exhaust can *always* be used. Beyond this point use duplex sets (motor and turbine driven) to take care of peak exhaust loads and, from there on, all motor drive. In this way the maximum possible efficiency is obtainable throughout.

As an alternative to the above, the exhaust from the auxiliaries may be controlled by the requirements of the heater and the surplus led to the low-pressure end of the main units.

In many quarters there is a strong sentiment in favor of the house turbine to improve the efficiency of the auxiliaries. This turbine consists of one medium sized generator unit, say of the bleeder type, which will supply just the requisite amount of exhaust steam for heating purposes, the remainder being taken to a condenser. From this generator is supplied electric current for all of the auxiliaries. While this system has its advantages from an economic standpoint, it does not overcome the strong disadvantages of electrically driven units in certain portions of the station where continuity of service is vital. For instance, it is obvious that boiler feed pumps should be furnished with steam direct from the boilers. Every piece of intervening mechanism, such as generator, motor, rheostat, etc., increases the danger of being unable to feed the boilers in the event of an electrical disturbance.

The water rate or efficiency of steam turbines, large or small, of course depends primarily on the velocity ratio of steam to wheel speed. The efficiency ratio of small turbines of different types will be found to follow closely the curves given in Fig. 2. In this same figure is plotted the efficiency ratio generally obtained by two-row impulse elements in the larger sizes. The difference between the two, and the reasons why, in practice, the curve for small machines does not more nearly approach that of the larger units, is explained as follows:

In the large machines one speed only is used for a given type of machine, say 1800 or 3600 r.p.m. The B.t.u. drop used in any one stage (say the high-pressure stage of a multi-stage machine)

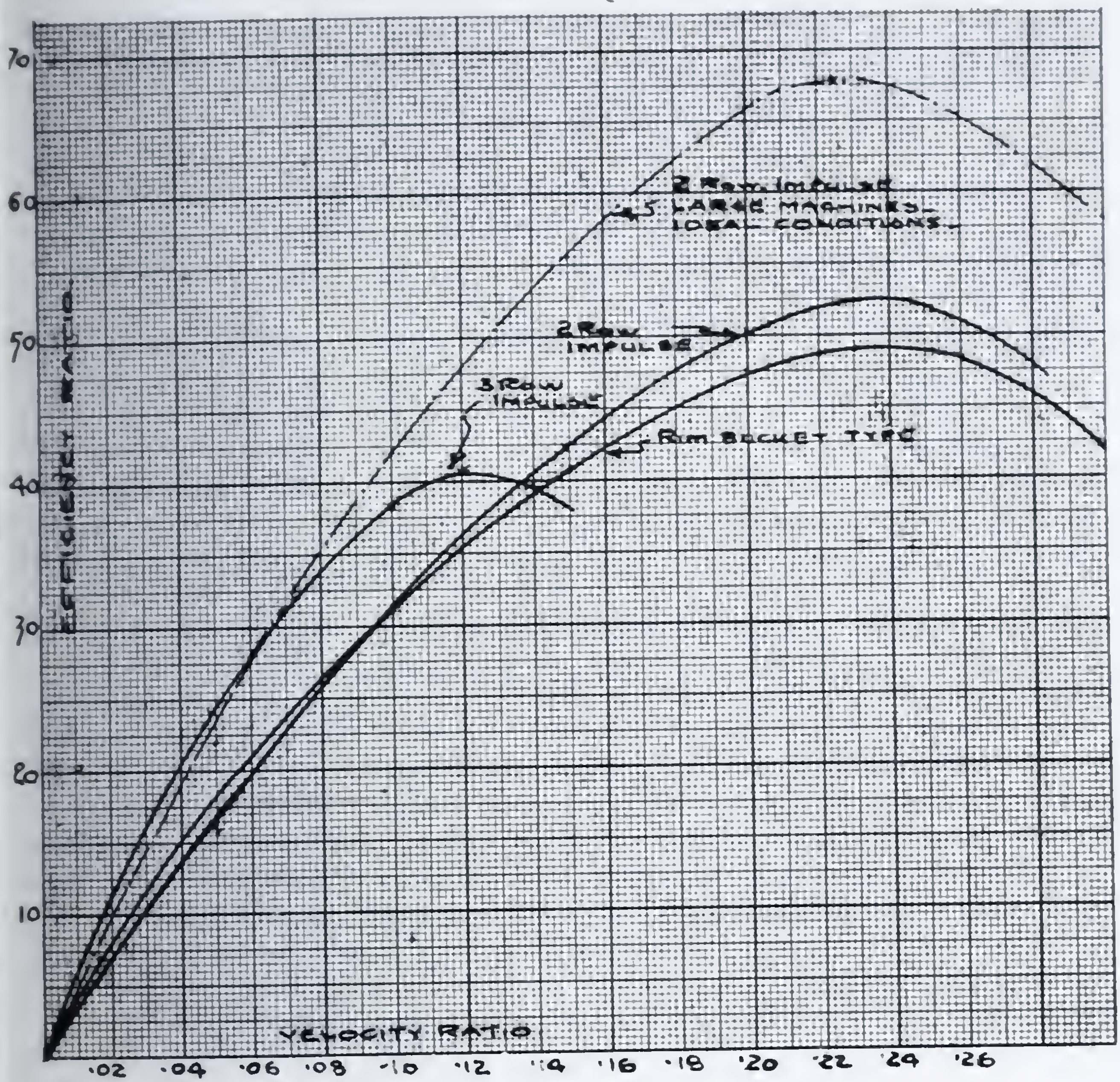

Fig. 2. Efficiency Ratio Curve of Different Types of Turbine.

is such that substantially all of the velocity energy can be used, and, therefore, theoretically correct blade angles can be employed. In the small machines a large speed range must be covered by each frame. With the exception of very high speed geared units the peak of the efficiency curve is never reached, and a compromise must therefore be made in the blade angles to suit commercial requirements.

Referring again to Fig. 1, the small amount of heat actually extracted by an auxiliary turbine is not generally appreciated, and where the exhaust can be reclaimed a large difference in water rate has surprisingly little effect on the heat balance, as will be seen by the following comparison:

TABLE I. EFFECT OF WATER RATE OF AUXILIARIES ON OVERALL FUEL CONSUMPTION WHERE EXHAUST STEAM CAN BE RECLAIMED

Steam conditions: 175 pounds, 75 degrees superheat, 2 pounds back-pressure.

1.	Total heat in steam. B.t.u.	1239.9	1239.9
2.	Heat at exhaust. Adiabatic expansion	1053.9	1053.9
3.	Heat available (1 — 2)	186.0	186.0
4.	Ideal water rate	13.6	13.6
5.	Efficiency ratio	0.25	0.50
6.	Actual water rate	54.4	27.2
7.	Heat extracted (3 × 5). B.t.u.	46.5	93.0
8.	Heat rejected (1 — 7)	1193.4	1146.9
9.	Per cent. of total heat extracted $\left(\frac{7}{1} \times 100\right)$	3.75	7.5
10.	10,000-kilowatt main unit. Water rate 12.2. Heat required	151,500,000	151,500,000
11.	Horse-power of auxiliaries, say five per cent.	500	500
12.	Heat required by auxiliaries (1 × 6 × 500)	33,800,000	16,900,000
13.	Heat returned to system (8 × 6 × 500)	32,500,000	16,250,000
14.	Heat chargeable to turbines	1,300,000	650,000
15.	Additional heat necessary. Case 1	650,000	....
16.	Total heat in two cases (10 + 14)	152,800,000	152,150,000
17.	Per cent. of increase. Case 1 $\frac{152{,}800 - 152{,}150 \times 100}{152{,}150}$	0.4	....

In this connection some very interesting data can be deduced on the oft mooted question of live versus exhaust steam heating. (See Appendix.)

The efficiency of any turbine, large or small, depends upon the velocity ratio between the steam and the wheel speeds. To improve the efficiency of the average machine running at commercial speeds, the following methods may be resorted to—larger wheel diameter; the use of gear reduction, thereby increasing the blade speed of the turbine; or the use of multi-stage machines.

The following table gives a wide range of designs and the water rates obtainable with different combinations. For the sake of comparison a single-stage geared unit is included.

TABLE II. APPROXIMATE WATER RATES WITH VARIOUS COMBINATIONS OF STAGES

Steam conditions: 175 pounds, 75 degrees superheat, 2 pounds back-pressure. Speed 1200 r.p.m., 24-inch wheels, throughout.

Three-stage:	Two-row impulse in each stage	54
Four-stage:	First stage, two rows; three stages, one row	60
Seven-stage:	First stage, two rows; six stages, one row	49
Single-stage:	3600 r.p.m. geared. Water rate, including gear losses....	35.5

For low-head pumps and other apparatus where the speed of the driven member is as low as 1000 or 1200 r.p.m., the geared unit presents distinct advantages. While it is entirely feasible, and good practice in some installations, to use direct connected units for these low speeds (actual water rate being of secondary consideration), where the horse-power is low, large wheel diameters are costly and introduce frictional losses which, in turn, practically counteract the increased efficiency due to higher tip speed. There is also the increased danger of excessive blade erosion due to poor relative nozzle and blade angles and the shock created thereby.

Referring to the table given above, it is hard to see where, if a geared unit is used, multi-stage practice should be resorted to except in the larger units.

The practical objections to multi-stage machines lie in the high pressure that must be carried in the first stage, and the difficulty experienced in designing a satisfactory gland or stuffing-box that will prevent leakage into the engine room. In addition to this the larger shaft span reduces the critical speed and in many types this is reduced to a point below the operating speed. The "passing through" of this critical speed may not be considered serious, provided always that the lowest operating speed is above the critical speed, but any whipping of the shaft must necessarily produce wear of the intermediate glands, eventually resulting in increased inter-stage leakage.

In the early part of this paper the statement was made that simplicity and reliability were the most essential factors to be considered in the design of auxiliary equipment. From a mechanical standpoint the objective is the fewest possible number of working parts. All designers of so-called complete equipments

such as turbo-generators, turbine pumps, etc., design the unit in such a way as to have only two bearings, this being sufficient with such equipment.

As the demand for turbine equipment increased, several makers entered the field, building small turbines only, and in like manner all of the pump builders designed centrifugal pumps as complete units for turbine drive. It became standard practice to buy the complete turbine and complete pump and connect these by the so-called flexible coupling. While these units were eminently successful, certain minor troubles developed, calling for modifications of the general system heretofore employed. In the first instance it came to be generally recognized that the flexible coupling would not permit complete independence of alignment of the two units at high speed, and the instruction books of all turbine makers are very specific in stating that the units must be lined up with extreme care so that all four bearings are dead in line, the possibility of play in the coupling not being considered. A further erroneous idea was prevalent that any cast-iron bed-plate was sufficiently rigid to keep the four bearings in line. As a matter of fact, it is now generally acknowledged that the average bed-plate can be sprung into any position desired, and the machines can be seriously thrown out of line due to tightening down the bolts indiscriminately. The majority of turbine makers and pump makers alike agree that a very large portion of the troubles that have been experienced can be directly or indirectly traced to the misalignment of the four bearings.

The advantages of the two-bearing unit are being more and more recognized, and the development in the field along these lines during the last few years has resulted in the successful introduction of several combinations consisting of a turbine built by one party and a pump by another. Several of these installations are now in operation in the United States Navy.

For land installations the type of turbine shown in Fig. 3 has been developed and has worked out very satisfactorily in practice. It will be seen from this illustration that the location of the bearings is practically the same as would be employed in a standard, self-contained, two-bearing pump. This unit is so designed that it can be applied to any design of driven apparatus, resulting

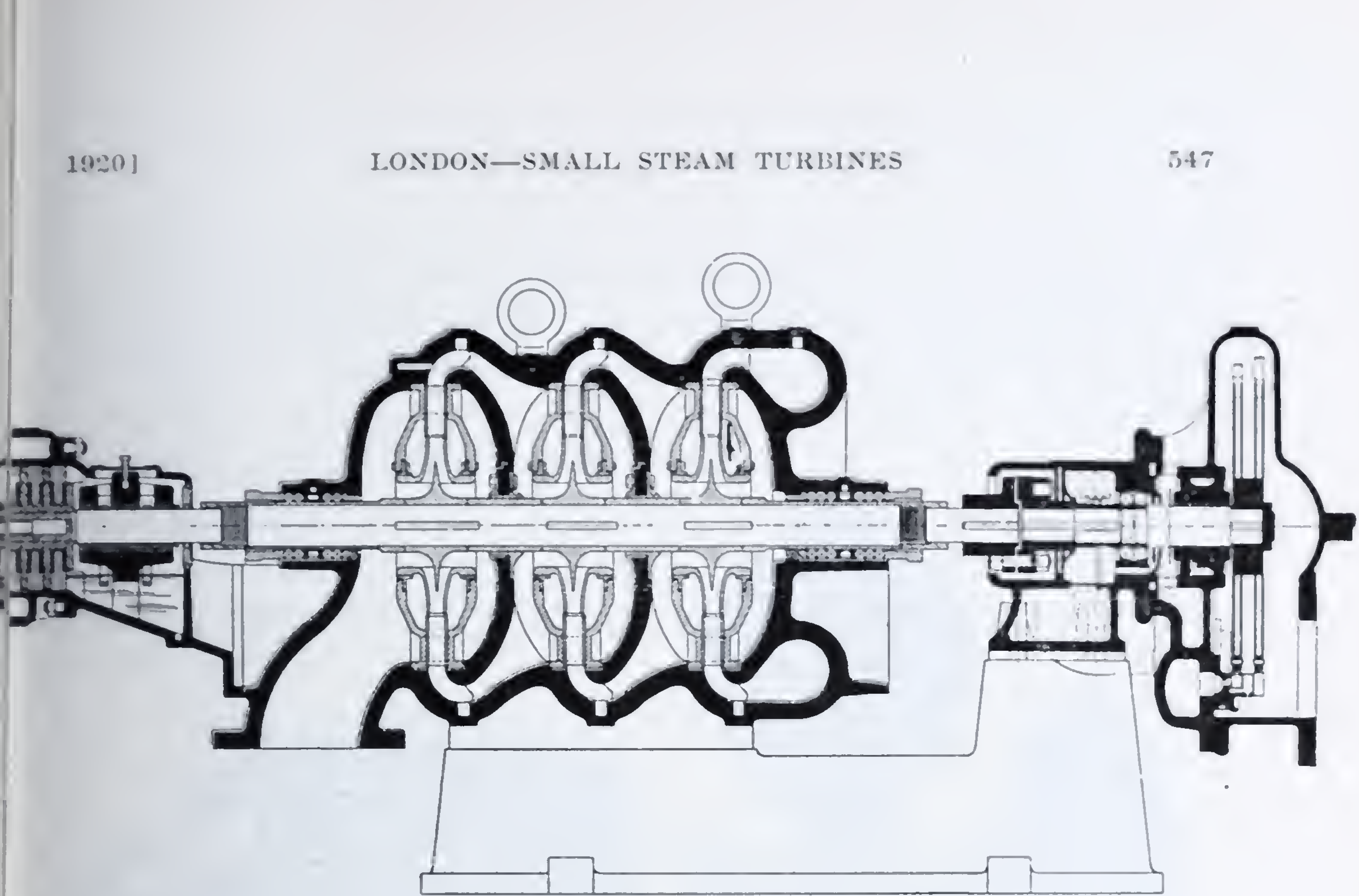

Fig. 3. Section through Pump Driven by Steam Motor.

in a "two-bearing overall" equipment eliminating the misalignment troubles mentioned above and the uncertainty of the flexible coupling.

In the design of the small turbine it was generally accepted that two or four feet placed under the turbine casing would be perfectly satisfactory; and this is true, provided the temperatures employed are not excessive, and also provided that due care is taken that the machine shall be lined up in its heated condition. With the increasing temperatures now prevalent in central-station practice, this design is by no means satisfactory and modifications have had to be made in the design of this apparently simple element. Temperatures up to 700 degrees F. are now becoming common practice. With a turbine having a wheel diameter of 36 inches, or the center-line approximately 24 inches above the foot of the turbine, the shaft will rise 0.1 of an inch with a temperature of 700 degrees F. This is far more than sufficient to throw the machine so out of line as to render it inoperative.

Various designs are employed where the feet are placed approximately on the center-line of the turbine. This satisfactorily takes care of vertical movement but does not prevent lateral misalignment. For instance, should the cradle supporting these feet be allowed to expand with the casing, an uneven casting will per-

mit one side to move more than another. The logical method of supporting a casing, therefore, is by a substantial flange at the center permitting free expansion in all directions as illustrated in Fig. 4.

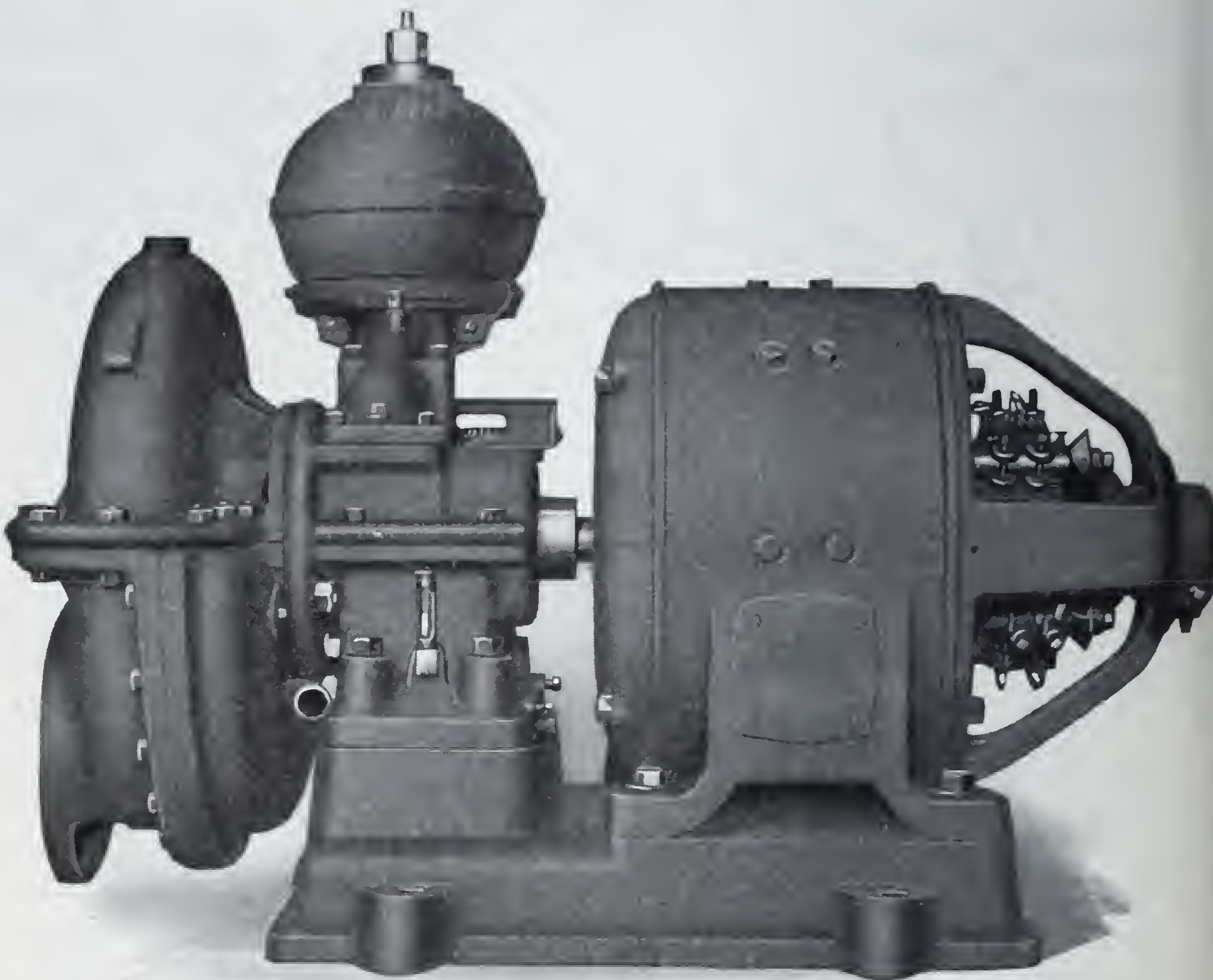

Fig. 4. Steam Motor Generator Set, Showing Centrally Suspended Turbine Casing.

In the design of geared turbine units many problems present themselves. In the earlier days of geared machines, the high degree of accuracy and workmanship necessary for the satisfactory operation of high tooth speeds was not obtainable, and this naturally resulted in considerable trouble with the gears themselves. During the last few years, however, gear-cutting machinery has reached a very high degree of perfection, and it may be broadly stated that practically all manufacturers of gears to-day build a commercially perfect gear. Sufficient experiments and tests have

been carried out to determine what are the safe limits of tooth pressure and speed. This last point, while of the greatest importance, is often considered the only factor entering into the satisfactory operation of such gears. Experience has demonstrated, however, that this is by no means the case; otherwise, trouble would not have developed in installations where there has been no reason whatever to doubt the accuracy of gears or the lineal pressure per inch of tooth face; these troubles, therefore, must result from some other cause.

Equally as important as the correct theoretical tooth pressure is the provision that must be made so that this tooth pressure may be uniformly maintained. This again brings us to the question of alignment of the gear itself relative to the driving member. As in the four-bearing pump or generator units, experience has shown that where trouble existed this could invariably be traced to misalignment of the turbine and the gear pinion shafts. The arguments mentioned above relative to the unsatisfactory operation of flexible couplings holds good again here. If the turbine is out of line with the gear pinion or the flexible coupling is not properly made; that is, if it is out of truth, misalignment results in a distortion of the pinion shaft resulting in noisy operation and wear of the gears.

That the probability of this condition actually occurring is generally accepted as serious is evidenced by the fact that the majority of makers are now redesigning their apparatus to eliminate this source of trouble. The three-bearing gear unit now built by several makers is an improvement over the four-bearing combination, but in this design great care must be taken so that the temperature of the turbine end will not distort the casing to such an extent as to throw the three bearings of the pinion shaft out of line.

To overcome the last possibility of outside influences affecting the alignment of the pinion and gear, the two-bearing pinion with an overhung turbine wheel is now being adopted by several makers (see Fig. 5) and as the load due to the turbine wheel is a determinable factor, the uncertainty of unknown external loads affecting the misalignment of the unit is entirely overcome. Actual service tests of these units has demonstrated the logic

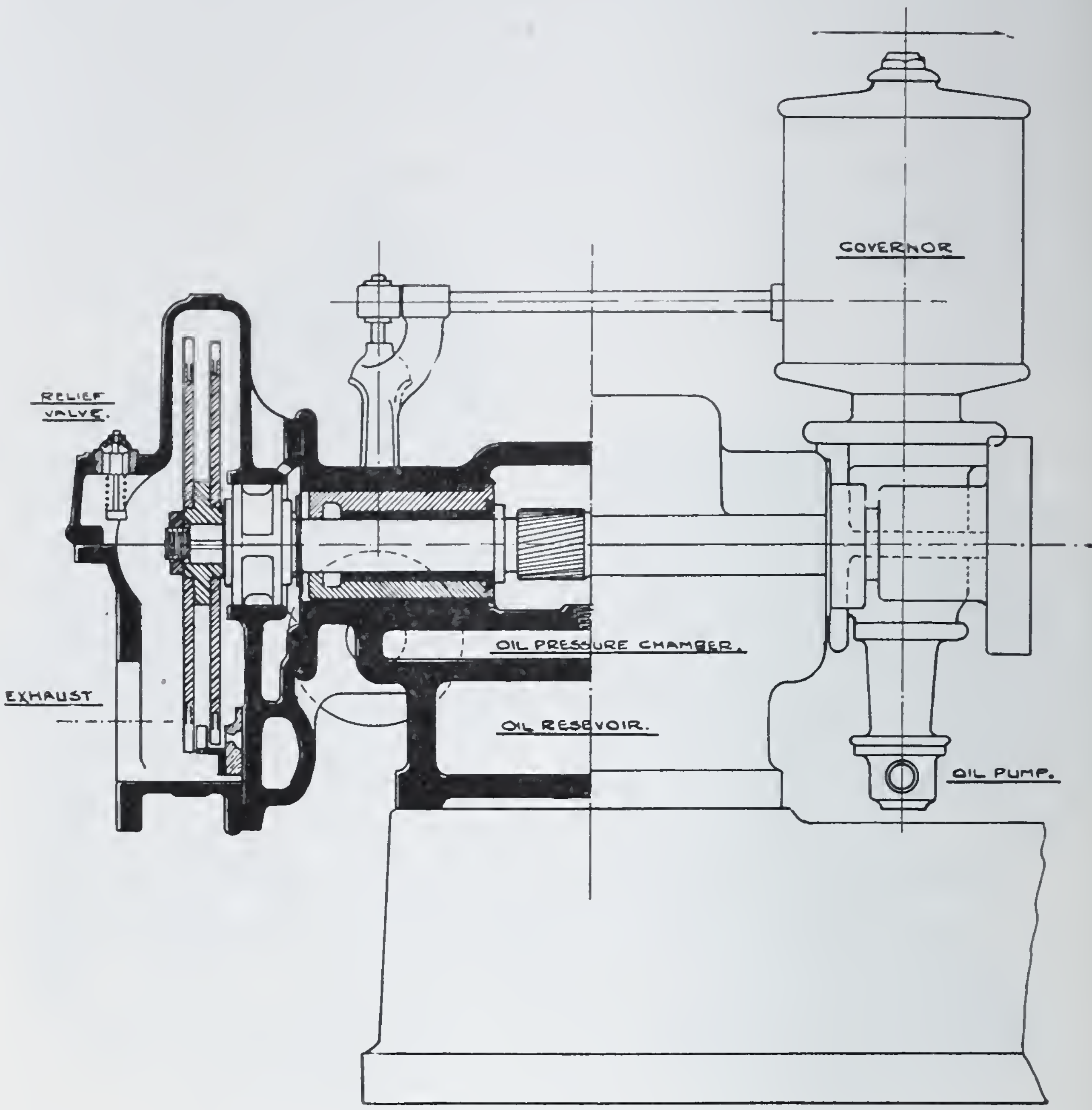

Fig. 5. Two-Bearing Gear Unit with Overhung Turbine Wheel.

of the above arguments should they at any time have been open to question.

The small turbine has more severe conditions to contend with than the larger units with regard to change in back-pressure conditions. In the larger units, conditions at the high- and low-pressure ends are practically constant. In the smaller machines, however, particularly for marine work, the glands must be designed so that the machine can be satisfactorily operated from the highest possible vacuum up to 15 or 20 pounds back-pressure. It must also be borne in mind that while it is quite simple to design a gland that will operate satisfactorily under any one given back-

pressure condition, it is not by any means such an easy proposition to design a universal gland that will operate under plus or minus pressures at the outside of the casing. Furthermore, it is highly desirable that these glands should be designed so that they require no lubrication. This is particularly the case in marine work or in conjunction with refrigerating machinery where the exhaust is used for making ice. Water sealed glands are satisfactory, only provided that pure water can be supplied to these glands. In the larger units this is entirely practicable inasmuch as the condensate can be used for this purpose. In the smaller units, however, pure water is not always easy to obtain. Furthermore, in small units the power absorbed by a water sealed gland, especially under high back-pressures or vacuum, is quite appreciable.

The double-labyrinth gland as used in larger turbines has more decided advantages over any other design for small machines, inasmuch as it is frictionless, requires no lubrication, and the design is applicable to all back-pressure conditions. To seal a comparatively long gland satisfactorily against high back-pressures has generally been supposed to be essential, and this is correct where the gland bushing or casing is made in one piece, as the distortion of this outer casing, due to the different temperatures at the two ends of the gland, increases the clearance; and this, in turn, results in the necessity for a great number of rings. In the design shown in Fig. 6 the packing rings of the labyrinth gland are divided up into sections, the contact point between the casing and the bushing being in the center of each segment. In this way the distortion is reduced so very materially that a comparatively short gland can be used. This gland is operating perfectly satisfactorily up to 20 pounds back-pressure, with, of course, a blow-off between the second and third segments but with absolutely no leakage from the outside segment into the engine room. This blow-off may be considered a disadvantage and may be considered as wasteful in steam. However, when compared with the cost of the lubricant that is used in many glands, the cost of this waste will be found to be materially less than the cost of equivalent oil lubrication.

Some interesting tests have been carried out on these glands

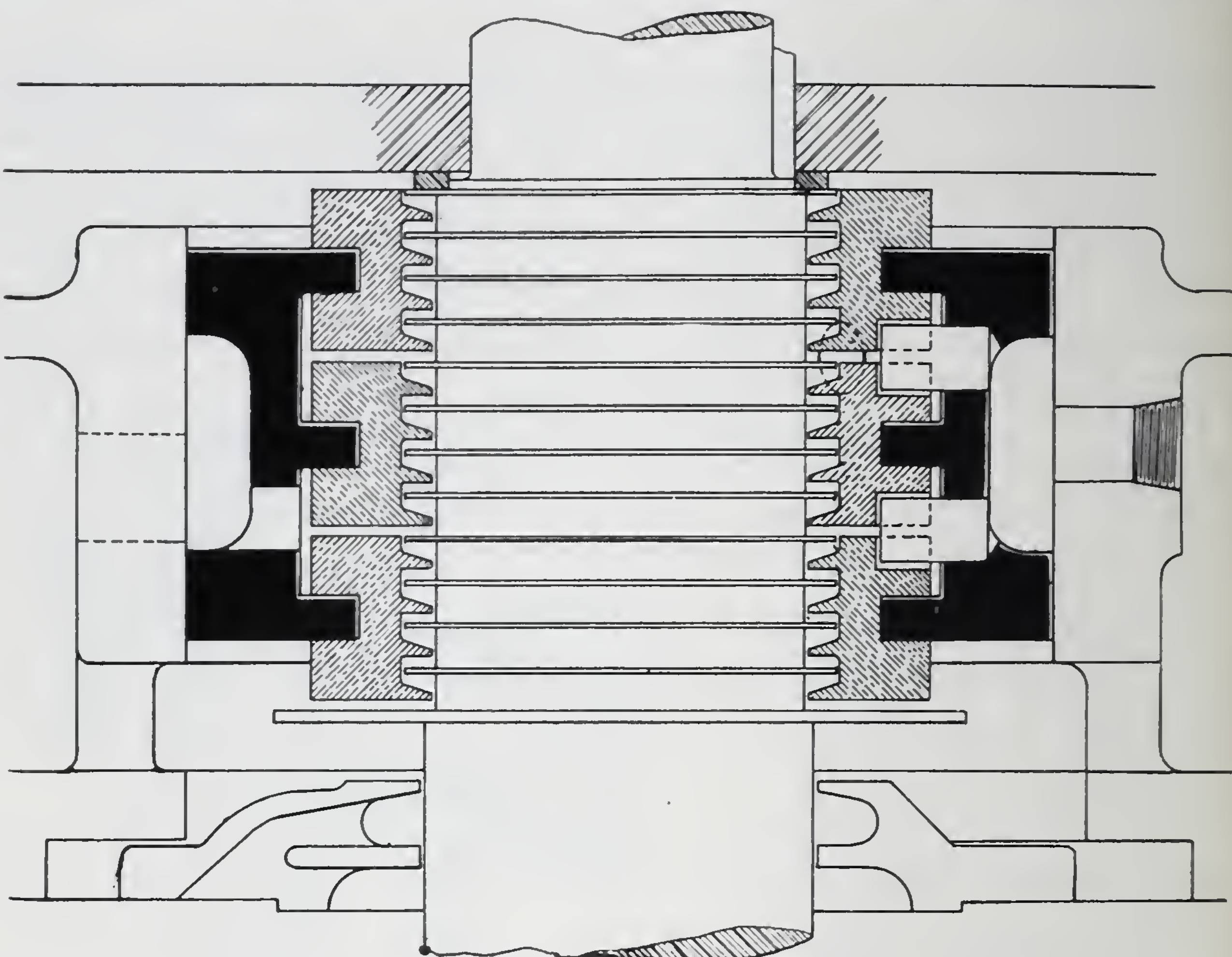

Fig. 6. Section through Double Labyrinth Gland.

after the machine has been in operation sufficiently long to allow everything to wear in, and these tests show a leakage of one pound per hour per pound back-pressure. Tests were carried out up to 20 pounds back-pressure and the line was substantially straight. In other words, with a back-pressure of 15 pounds the leakage would be 15 pounds per hour. It must be borne in mind that this steam is clean and can be carried away to the hot-well.

There are several designs of flexible couplings now on the market, some of which allow greater ease of manipulation than others, but many permit of no flexibility at all when operating at high speed. It is not a difficult matter to see wherein several of these designs fail when operated at turbine speeds. Take, for instance, a turbine running at 3600 r.p.m., the turbine and driven member being out of line. There must be a reciprocating motion of 60 complete strokes per second at the pins of this coupling. As the majority of these couplings are operated without lubrication one of two conditions must exist; they either work, in which condition they would wear out in a very short time, or the parts do not reciprocate, the coupling therefore remaining rigid. Should the claims made for flexible couplings actually work out in prac-

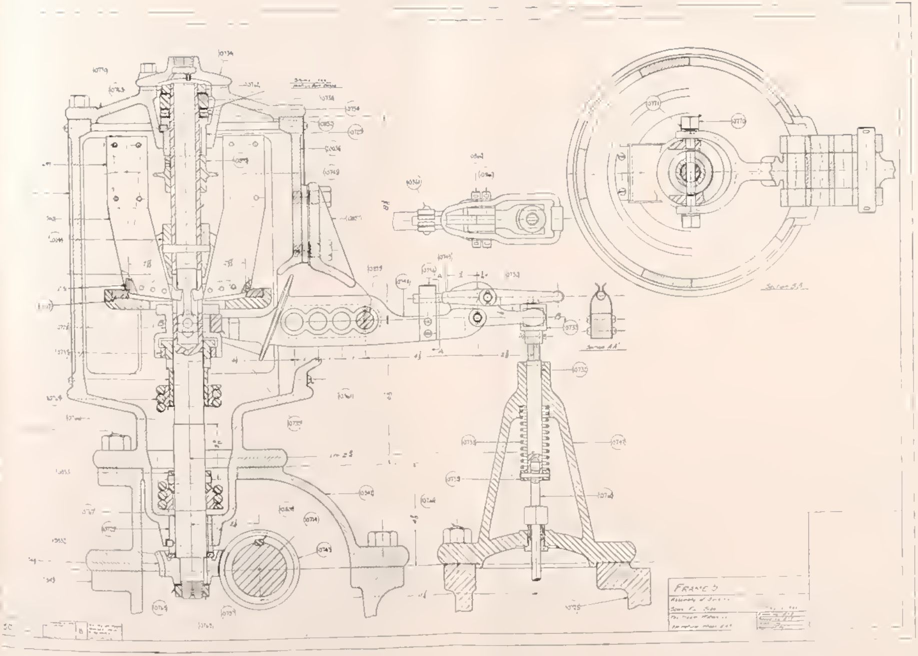

Fig 7. New Design of Constant-Speed Governor.

tice there would be no necessity for the implicit instructions issued by turbine makers regarding the alignment of all of their units.

In small turbine practice the direct-connected governor is more generally adopted than the low-speed geared type, primarily because of its *apparent* simplicity and the elimination of any necessary gearing. With this type of governor, there are, however, one or two certain disadvantages that more than offset the apparent simplicity. In the first place, a governor at high speed is necessarily very sensitive. In the larger machines it is now generally accepted that with very few exceptions the old idea of obtaining a regulation of two per cent. is to be avoided rather than attempted. This is especially true when machines are to run in parallel. Stability of regulation is far more important than close regulation. Constant voltage can be obtained with modern generators by proper compounding over a comparatively wide speed variation.

What is true of larger machines is equally so with the smaller sizes. For pump or blower units any reasonable speed variation is satisfactory and with properly compounded generators, a speed variation of four per cent. is much more satisfactory in practice than the close regulation of two per cent. With the high-speed governors it is much easier to obtain 1.5 to two per cent. speed variation than it is to obtain anything wider, on account of the small dimensions of the governor that must be used and the limitations of overhung weight and unbalanced forces. Consequently, it is hard to overcome sensitive operation with this type of regulator and hunting troubles are very frequent and difficult to overcome. Again, with the shaft type of governor, the limit of travel is very small—perhaps 1/8 of an inch for a two-inch valve—and any slight movement of the shaft at once affects the governor. For instance, a shaft travel of 1/32 of an inch is approximately equivalent to a change of load of 25 per cent. On the other hand, with a geared type, a longer governor travel is obtainable, with consequently more stability; and it is in no way affected by the endwise movement of the shaft. For small machines, the Pickering type of governor gives excellent results; primarily on account of its simplicity, and secondly because of its very stable operation. The characteristic of this type of governor,

however, is such that it is applicable only with small ranges of travel, and for larger units the orthodox central-spring type is desirable.

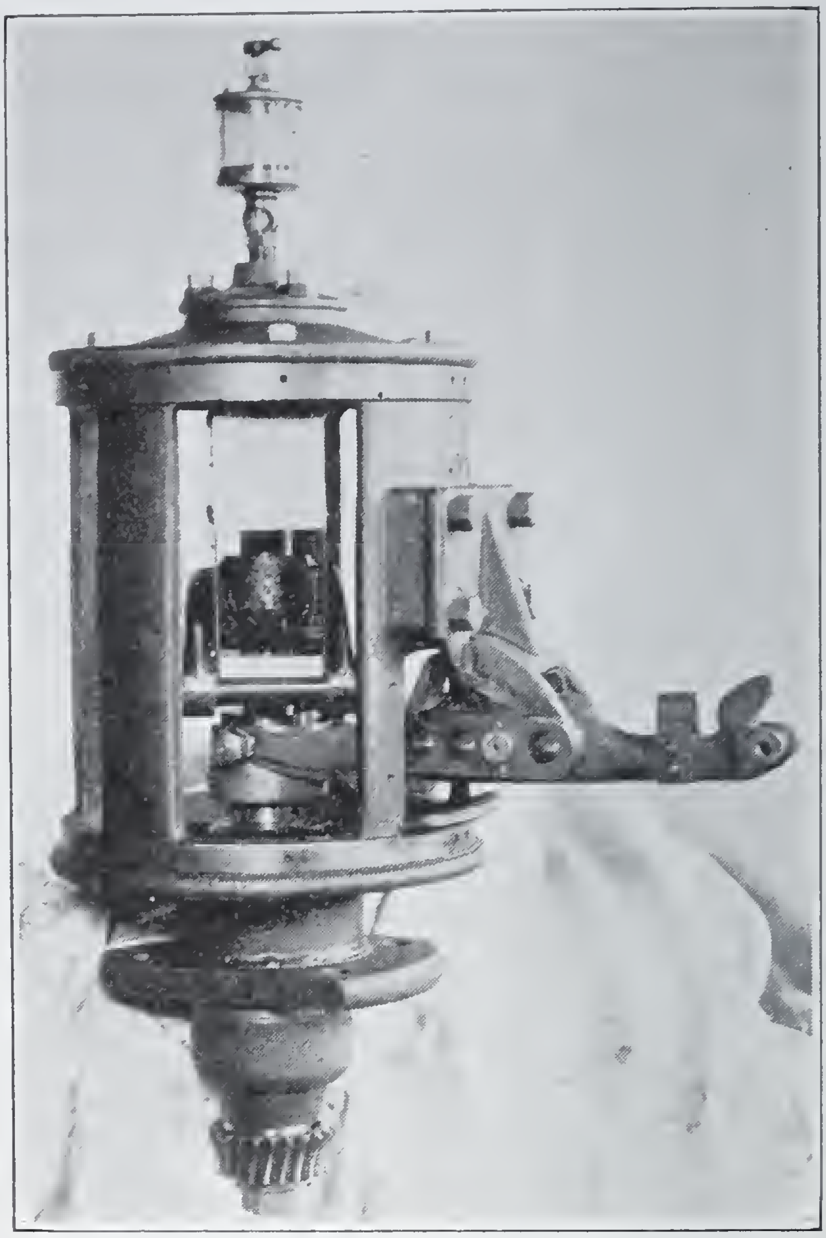

Fig. 8. Governor Shown in Fig. 7.

In the design of governor in Fig. 7 (insert) and 8 some interesting features have been introduced. A tension spring has been substituted for the compression spring which modification has obvious advantages as the tension spring does not buckle under load. This particular design of governor drive permits of this tension spring being used without lengthening the whole governor mechanism. Again, this governor is designed as a unit having a substantial bearing at the top and bottom and the whole governor can be assembled and tested as a unit independent of the turbine itself. The light side plates used for supporting the weights have the effect of concentrating the *effective* weights so that they oper-

ate in substantially a straight line, giving a known characteristic which is difficult to obtain where the arms supporting the weights in themselves produce effective centrifugal forces.

In designing governors for satisfactory regulation the governor head is by no means the whole problem. The design of valve is probably responsible for more governor troubles than anything else. The design of a perfectly balanced valve presents many problems. A valve having seats of two different diameters is obviously unsatisfactory. The split-seated valves give as near a balanced condition as possible but they are expensive and are awkward for replacing. The design of valve as shown in Fig. 9

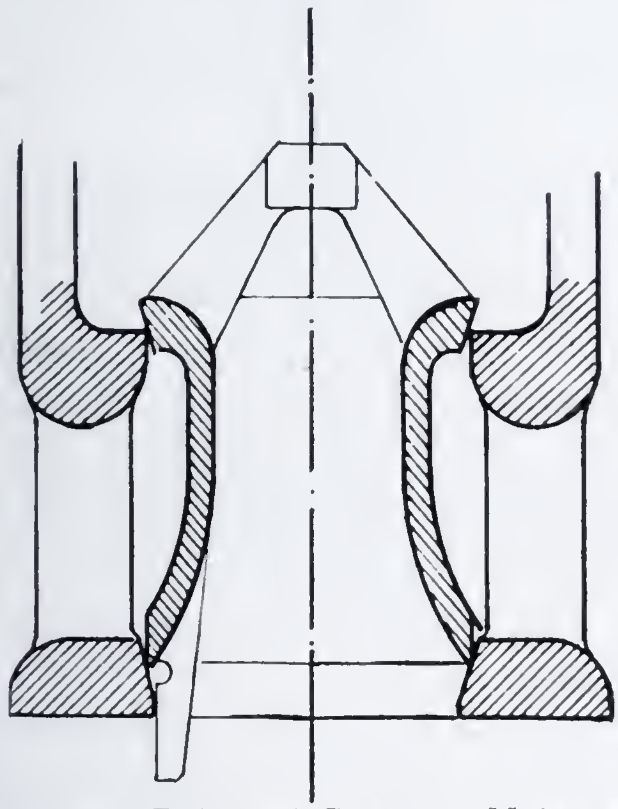

Fig. 9. Section through Balanced Governor Valve without Split Seats.

gives perhaps as close an approximation to a balanced valve as is possible with any valve without loose seats. It will be noted in this design that the steam enters at the center and the bottom valve basket seat is tapered, with a straight seat on the valve itself. In the top seat the order is reversed. In this way the valve can be let down into the basket and, when closed, the pressure on the upper seat is equivalent to that of the lower seat. One important feature to be borne in mind in all valves of this description is the advantage of keeping the taper on the valve-seats as steep as possible. This gives a wider opening at low loads than would be necessary were flatter angles used; this, in turn,

reducing cutting due to wire drawing.

No matter what refinements are made to insure a perfectly balanced valve the velocities existent in the valve are an unknown factor. Up to a three-inch valve where good regulation is required it is practicable to connect the governor directly with the valve, using a reasonably powerful governor. Beyond this point, either the governor must be abnormally large, which of course is a good fault, or a relay mechanism should be introduced allowing free action of the governor with a powerful supplementary control of the valve.

Discussion of the characteristics of ball-bearings may look somewhat irrelevant in a paper on steam-turbines, and some explanation of the reason for introducing the subject may therefore be advisable.

When designing the first single-bearing turbine that would be applicable to any type of driven apparatus, the type of bearing that could be satisfactorily employed naturally demanded first consideration. The problem that presented itself was that this bearing must be capable of standing any load produced by any driven member. This bearing should be capable of taking unknown end thrust, and commercially it was highly desirable that one type of bearing should be employed which would not be unwieldly for small units and yet have sufficient capacity to take care of the majority of propositions.

The ball-bearing presented great possibilities, provided it could be satisfactorily operated at turbine speed. Ball-bearings had previously been operated on centrifugal pumps and similar machinery but with questionable success. An investigation, however, satisfactorily explained why these previous installations had been unsuccessful. In the first place, the type of bearing generally used was not suitable for high-speed operation. Referring to Fig. 10 it will be seen that this bearing is what is known as the standard single-row type. This type does not permit of any shaft deflection and since all high-speed shafts deflect and sometimes whip, the punishment on the balls is severe. One other dangerous point about ball-bearings of this nature is that it is possible to have two bearings out of line and still have the shaft turn freely. The condition that actually exists in this case is that the balls are

Fig. 10. Standard Single-Row Ball-Bearing.

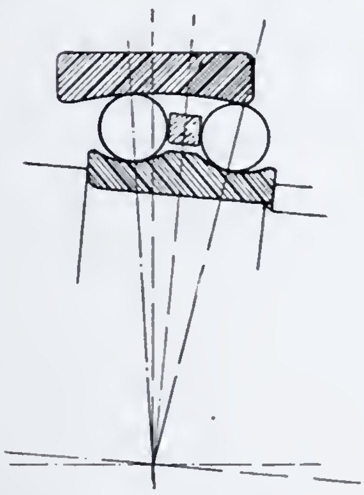

Fig. 11. Self-Aligning Type Ball-Bearing.

initially severely overloaded without this being apparent in any way.

The design of bearing shown in Fig. 11 was therefore decided upon as having characteristics which overcame the difficulties of the earlier design and at the same time had high radial and thrust load capacities.

In subsequent designs the type of ball-bearing shown in Fig. 12 has been used in cases where excessive thrust capacity only is necessary and where the actual deflection of the shaft is small. The operation of ball-bearings of this design has been eminently successful, but this has been due to a careful study of what actually takes place in ball-bearings themselves at high speed. The manufacturers of ball-bearings were unable to give us any reliable data relative to the speeds and loads that we were anticipating, and so a careful analysis of the whole problem on our own part was necessary. This analysis brought out some very interesting points. As our deductions are somewhat radical when compared

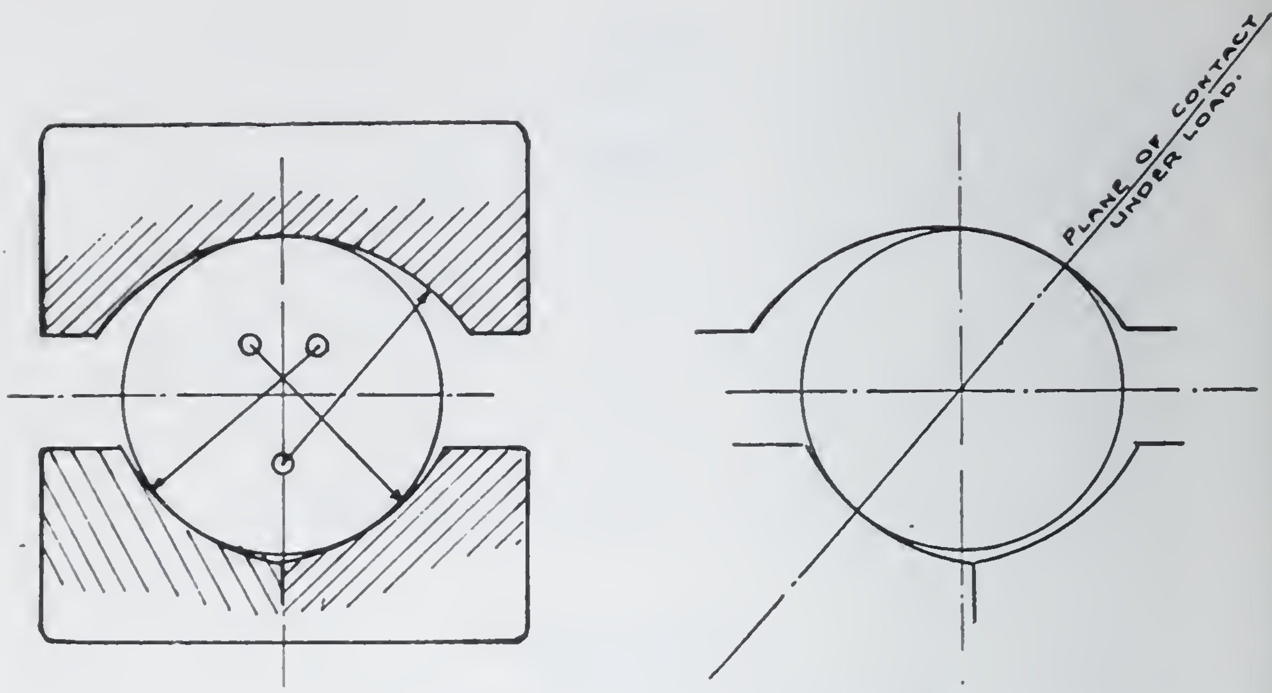

Fig. 12. Type of Ball-Bearing for Taking Radial and Thrust Loads.

with the orthodox ball-bearing data, the writer thinks his observations on this subject may be of interest to the members who are considering ball-bearings for their high-speed machinery.

The limit of speed of a theoretically perfect ball-bearing is reached when the journal load plus the centrifugal force of the balls is such that it will crush the material in the balls or races. As an example, the actual crushing load on the balls in a three-inch mean diameter bearing having ⅝-inch balls, is reached with a speed in excess of 100,000 r.p.m. at no load. The reluctance with which ball-bearing makers give guarantees regarding their bearings at commercial speeds of 3000 to 4000 r.p.m. naturally led to an investigation as to what actually was a safe speed limit for ball-bearings.

From the above figures we can entirely eliminate the actual performance of the balls in the races. Many authorities in writing on ball-bearings actually state that speed is of no consequence. Furthermore, it is stated correctly, that with a theoretically perfect ball-bearing no lubrication is necessary, as perfect rolling contact exists; but it is impossible to make a perfect ball-bearing, inasmuch as a retainer must be introduced. The limits must therefore obviously lie in the performance of the balls in this retainer. The retainer consists of a series of small bearings against which the balls rub to drive the retainer around. Bearing this in mind, we have one of two conditions:

1. A frictionless retainer in which there is no tendency to retard the rotation of the balls.
2. A retainer sufficiently lubricated so that a constant oil film is maintained between the balls and retainer to approach as nearly as possible condition 1.

The circumferential speed of the balls and also the retainer in a three-inch mean diameter bearing running at 3600 r.p.m. is 1430 r.p.m. With ⅝-inch balls the peripheral speed of the balls is, therefore, about 37 feet per second. This is considered a pretty good high speed for ring lubricated bearings, but it is generally understand that there is no load on these bearings, therefore this speed of 37 feet per second does not mean anything. However, there is a limit to the speed at which any two metals may be run together (especially when no anti-friction metal is introduced) practically irrespective of the load. But the supposition that there is no load on this retainer is erroneous. Unless extreme care is taken in the design and manufacture of the retainer itself and unless it remains concentric this retainer will produce unbalanced loads. This at once creates a deliberate bearing load between the balls and retainer. As the bearing surface between the balls and each section of the retainer is in itself very small; and, due to the changing circumferential pitch of the balls when operating under load, it is possible for all of the load due to the unbalanced retainer to be transmitted to one bearing point, it will be seen at once that a very slight unbalanced load is necessary to bring the actual load per square inch on the bearing surface of the retainer up to a very high figure. The writer has found this to be the actual case in practice.

In one certain type of ball-bearing of the proportions given above, the retainer actually weighs about four ounces. It is of course difficult to measure or even closely approximate the actual bearing surface in the retainer but from a careful examination of several ball-bearings the writer ventures the statement that an area of about 0.030 square inch at each ball is sufficiently accurate for a discussion of the points at issue.

Now let us assume standard bearing practice and allow a comfortable load of 30 pounds per square inch; the actual safe load, therefore, on one contact point of the retainer will be 0.9

pounds. Now one pound unbalanced load at 1430 r.p.m. at the radius given, creates a centrifugal force of 87 pounds; therefore, the amount of unbalance to produce 0.9 of a pound or 30 pounds per square inch on the bearing is 0.0135 pound or five per cent. of the weight of the retainer. It will be easily seen that with the clearance allowed in ball-bearing retainers with a retainer weighing four ounces it is very easy to produce a condition where, unless adequate lubrication is provided, excessive friction will take place between the balls and the retainers thus retarding the rotation of the balls and shortening the life of the bearing.

The solution of this problem, then, is a very carefully designed lubricating system. This fact entirely explodes the idea that for ball-bearings at high speed a drop of oil or a lump of grease is all that is necessary. On the contrary, the bearing must be lubricated just the same as a sleeve bearing, because we have in effect nothing but a series of sleeves which must of necessity be provided with on oil film to prevent friction. Not only is it necessary to feed oil to these bearings but it is equally necessary to lead the oil away from the bearing after it has been heated up. The system employed for lubrication of the bearings in the steam motor shown in Fig. 13 is probably solely responsible for the successful operation that we have had with this type of bearing. The oil is fed to the bearing exactly as though it were a sleeve bearing and is led away to a settling and cooling tank. In other words, the bearing is treated exactly as though it were a sleeve bearing and in the writer's opinion this is the only way to consider it.

Other important factors, of course, enter in; such as the purity of the oil for the purpose of preventing any chemical action that will injure the surfaces of the balls and races. Again, the bearing must be kept absolutely free from grit. The circulating system suggested above has the advantage of fulfilling this function.

In the writer's opinion there is yet a good deal to be learned from research and investigation before any satisfactory data or formula can be deduced which will give us authentic data regarding the limitation of ball-bearings. The great demand for commercial ball-bearings which actually operate satisfactorily under given conditions, is probably responsible for the lack of research

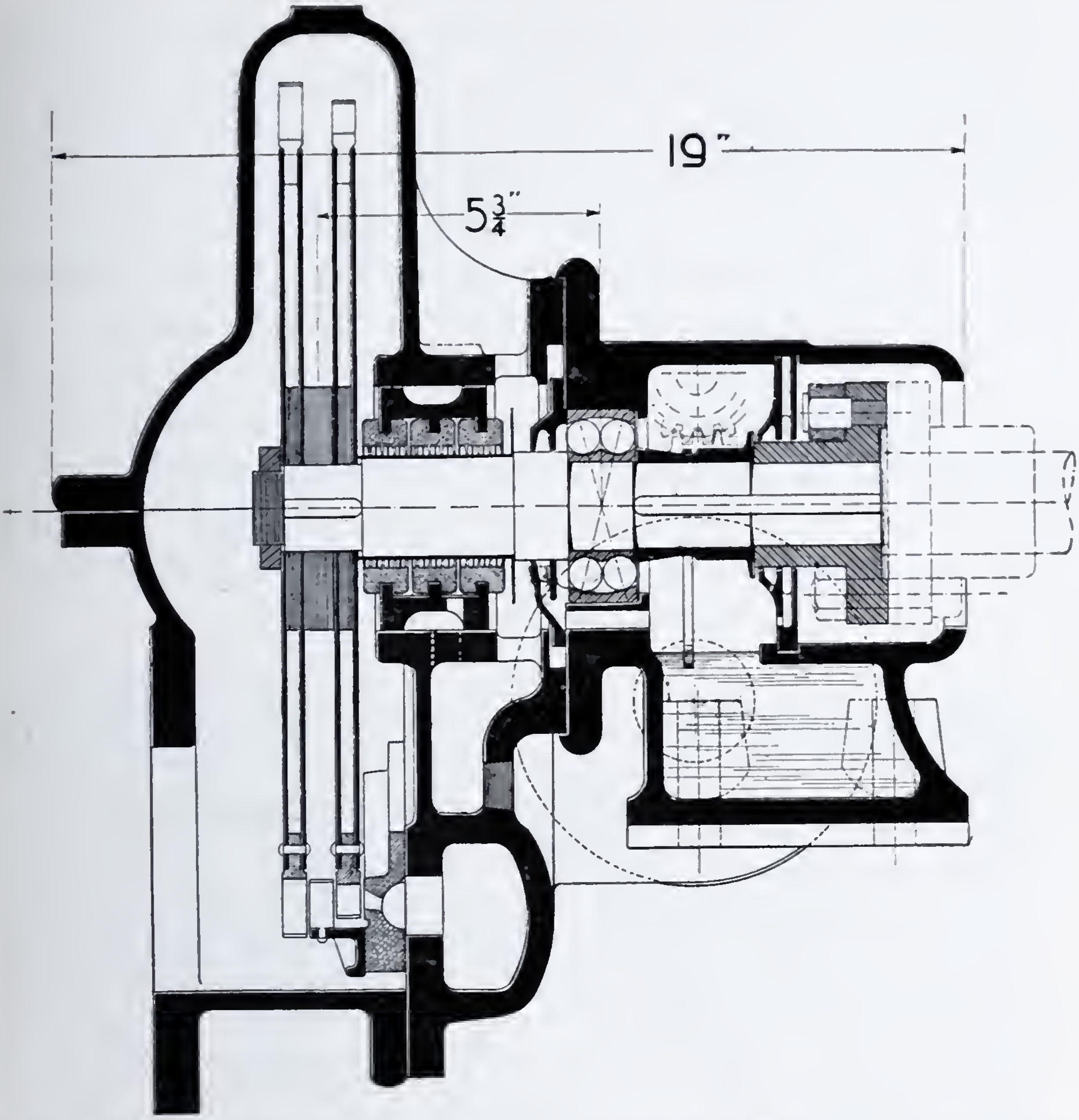

Fig. 13. Section through Steam Motor Showing Method of Lubricating Ball-Bearing.

work that has been carried out in a field which is naturally less remunerative.

The writer realizes that the conditions cited relative to loads on ball-bearing retainers are extreme, inasmuch as the load at each segment is probably momentary. The arguments advanced further are not intended to depreciate the advantages of ball-bearings at high speed. On the contrary, the writer is a firm believer in the possibilities, based on the success he has personally experienced; but, unless the ball-bearing makers themselves see their way clear to issue more authentic data relative to permissible loads and speeds, it behooves the user of ball-bearings to employ his own engineering judgment, based on the simple facts of the case.

APPENDIX

The question of relative efficiency between live steam and exhaust steam heating has been extensively discussed in the scientific press and before various engineering societies.

It has been stated that fuel consumption when operating with live steam is the same as when the steam has been taken from an engine and an equivalent heating obtained from the exhaust. Any statement to the effect that something can be obtained from nothing is obviously wrong, but an analysis of the condition actually existing with live and exhaust steam heating will show why it is not only possible but highly probable that in specific tests made under the two conditions the net result fails to show any difference between the two systems.

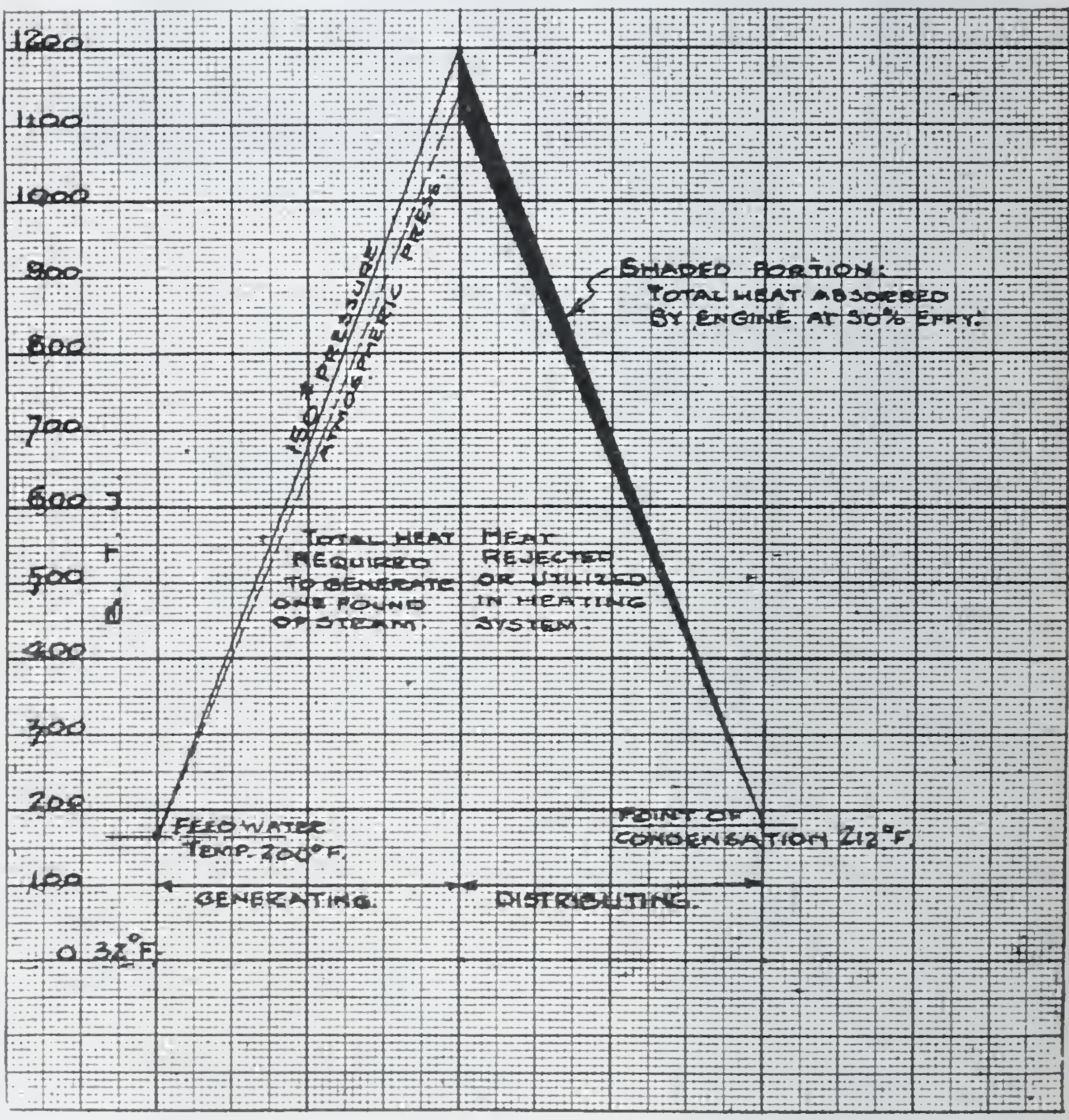

Fig. 14. Diagram Showing Total Heat Extracted by a Non-Condensing Engine or Turbine.

Referring to Fig. 14, the left-hand triangles show the amount of heat that must be added to a pound of water to generate steam. The dotted line represents steam at atmospheric pressure while the full line represents steam at 150 pounds pressure. In the right-hand triangle the shaded portion represents the total amount of heat taken away from a turbine or engine having an efficiency of 50 per cent. This, in turn, represents about 9 per cent. of the total heat. Very few auxiliaries or small machines have an average operating efficiency of more than 30 per cent., so that the actual heat extracted by the turbine or engine will in actual practice, in all probability, be in the neighborhood of five or six per cent.

If a week's test is run in any station to determine the relative efficiency of both systems, this test will in all probability not be accurate within about five per cent., so unless these tests are carried out on a laboratory basis and with infinite care to keep conditions absolutely identical during both tests, the errors of observation will be greater than the actual net difference that could be expected under the two conditions. This unquestionably explains why statements have been made to the effect that to use high steam through an engine or turbine and use the exhaust for heating is just as economical as it is to use the steam direct from the boiler to the heating system.

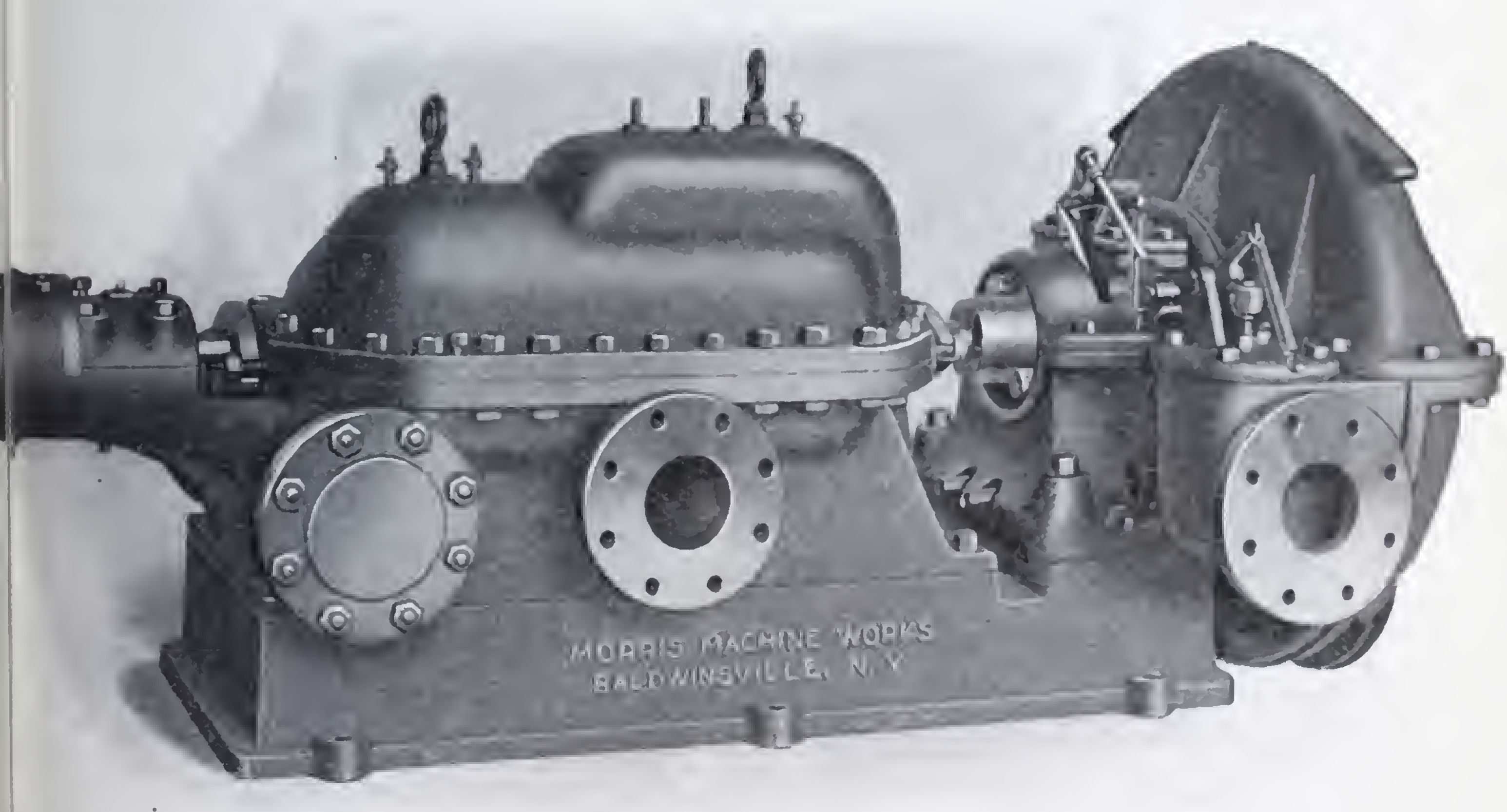

Fig. 15. Boiler Feed Pump Driven by Steam Motor.

DISCUSSION

Mr. J. A. MacMurchy:* I am very much interested in Mr. London's list of the factors to be considered in choosing a small turbine and the order of their importance. There can be no question that the auxiliaries in a power-plant must above everything else be reliable. It is, of course, desirable that they be of very simple design so that the operator can easily understand the manner in which the machine functions but I feel that in many cases efficiency should be considered as more important than that of first cost.

The general statement that with a given wheel diameter, a given speed, and the same type of turbine, the actual steam consumption will be practically identical irrespective of maker, is in my experience not borne out by experience, unless variations of 10 or 15 per cent. be considered as practically identical. Practically all turbine builders understand how to design turbines to obtain efficiency, but not all of them are willing to turn out a high-class finish on nozzles and blades, and other parts of the turbine, which have a very considerable effect on the efficiency.

For some years I have supported Mr. London in his contention that the so-called flexible coupling does not take care of much misalignment, but in many cases it is necessary to couple a turbine, which is complete in itself, to the driven apparatus, and we find that some of the modern so-called flexible couplings do operate quite satisfactorily with such accuracy of alignment as is obtainable from the ordinary workman. In order to maintain this alignment when operating with high temperatures, we find that the practice of supporting the turbine at the center-line is extremely satisfactory and I have never known of trouble being experienced due to one of the supports being somewhat stiffer than the other.

I have built a great many turbines which were coupled solidly to the pinion shaft of a reduction gear, but the bearing on the tur-

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bine adjacent to the gear is omitted, which leaves two bearings on the pinion and one on the turbine. The two bearings on the pinion are relatively so close together that it is scarcely different from a two-bearing construction. The results obtained have been uniformly excellent.

I find water glands to be the most satisfactory gland for use on a turbine in nearly every application. They seal right when the unit is new and they seal just as well as time goes by. Where the back-pressure is high it helps to add a labyrinth to reduce the pressure against which the paddle wheel seals.

I note that Mr. London does not approve of shaft-governors but the shaft-governor is so simple—obviating the necessity of any driving gear—that I find it a very suitable type of governor for a turbine to drive pumps or blowers. Not all shaft-governors are good governors but it is quite possible to make a shaft-governor entirely satisfactory for ordinary use.

Mr. Francis Hodgkinson:* We have listened to a very interesting paper. Mr. London has exhibited a number of designs of small turbines which show care and thought in detailed design, in which Mr. London is particularly capable, and which no doubt will result in very satisfactory operating machines.

I thoroughly sympathize with Mr. London on the subject of so-called "flexible couplings." No doubt it is desirable to eliminate them, and nothing can be more satisfactory than having the combined rotors carried on two bearings—whether it be a turbine with generator or pump, or a motor-generator set—providing the shaft may be designed with the requisite minimum deflection to avoid critical speeds.

I do not concur with Mr. London in his general proscriptions concerning flexible couplings. Many of those on the market are arrantly bad. There are some—one or two—however, that may be regarded as good.

Concerning governors, Mr. London is undoubtedly right in preferring the governor geared to the turbine an operating at a lower speed than the turbine itself, if good regulation is a consideration. There is a best speed for which a governor of a given

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strength ought to be designed and where the mass of the governor weights is concentrated at one point and not materially influenced by the masses of the arms supporting the weights. When designed for increased speed, the mass of the governor weights becomes less and the supporting arms greater, which precludes the governor having a straight-line regulating characteristic, rendering close regulation impossible without instability. However, there are many applications for small turbines where close regulation is not necessary and where a governor may be carried directly by the turbine shaft with reduction of cost.

Concerning the use of small turbines for driving auxiliaries, Mr. London would have us believe that their steam consumption is unimportant so long as the exhaust is condensed in the feed-water heater. This is true enough if our power-house is laid out to have steam-driven auxiliaries and there are provided no other means of heating feed water, but the modern power-house is not likely to be so designed. In large power-houses of earlier date, auxiliaries were electrically driven, and many troubles were experienced due to failure of the motors and their circuits. This brought about the general practice of employing steam-driven auxiliaries, using their exhaust to heat the feed water; and it was properly argued, as Mr. London has done, that so long as all this exhaust was condensed in the feed-water heater, the thermal efficiency of the process would be in the neighborhood of 90 per cent., and therefore, the steam consumption per horse-power of the auxiliaries was unimportant. The same argument would still fairly hold if live steam were used for feed heating. However, the greater the useful energy obtained from the steam in expanding down to the feed-water heater pressure, the greater the overall economy of the plant.

Unquestionably, steam auxiliaries, because of the steam, exhaust pipes, drips, drains, etc., render the basement dirty and unsightly, and are not conducive to good care and maintenance; but nowadays, motors and their circuits are considered as rugged and reliable as the steam-turbine, and their employment removes the above objections besides bringing about a great simplification of piping, etc.

In the design of a power-plant, continuity of operation must

be the first consideration, and economy the second, and a strong plea for the steam-driven auxiliaries is that they will be undisturbed in the event of trouble with the main units or electrical distrubances in the system, at which time it means a great deal if the auxiliaries can be depended upon to operate without attention. This thought has brought out the practice, as has been pointed out, of having the boiler feed pumps always steam driven.

It has lately become quite customary to operate auxiliaries electrically driven from a so-called "house turbine," which might be regarded as an additional power-plant for furnishing electric energy for the operation of all auxiliaries, the exhaust steam from which is condensed in a feed-water heater. A further development of this is to drive the generator both by a turbine and a motor, the latter energized from the main bus, the turbine being controlled by the pressure in its exhaust, thus maintaining a complete heat balance.

If the service to the bus bars may be regarded as sufficiently reliable, unquestionably the greatest overall economy is to be secured by operating the auxiliaries from the main bus system and bleeding the main turbine unit at one or two stages—preferably two—for heating the feed water by stages to the desired temperature.

I think Mr. London's discussion of the subject of ball-bearings is of much interest, and it gives to me, at least, some new light on the subject.

Mr. H. A. Rapelye:* It is a good deal of a presumption for me to talk about steam-turbines after Mr. London and Mr. Hodgkinson. I think we are very fortunate to have had the paper by Mr. London. I had an opportunity to read the paper and naturally was very much interested, not only in what he had to say about his particular turbine, but also because I had the good fortune to be associated with him in the turbine business for some years. Mr. London's is primarily a turbine for driving auxiliary apparatus.

While I think everybody likes the idea of getting away from as many bearings as possible, I feel there is at least one class of

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auxiliary in which the two-bearing unit is not going to be very satisfactory. I refer to variable speed fans for forced draft service where considerations of critical speed will almost preclude the use of this kind of a machine. In the two-bearing unit with overhung turbine wheel, the relation between first and second critical (which generally concerns you), and the third (which sometimes concerns you) is not very good.

I like Mr. London's idea about supporting the turbine casing in the center. I do feel, however, that in auxiliary apparatus there is something even more important: Mr. London's design lends itself very nicely to expansion of the turbine casing in any direction from the central support, but necessitates the location of the exhaust pipe flange remote from this support. It is always recommended, in fact required, in the instructions of small turbine builders, that piping stress must be kept off the casing. Yet this is almost never realized, and the advantage of the center casing support, therefore, is obtained only by the compromise of undesirable location of piping connections.

Mr. G. G. Bell:* I have listened with much interest to Mr. London's paper explaining his views on the design and construction of small turbines that can be satisfactorily worked with high-pressure and high-temperature steam. Mr. Hodgkinson has commented on the design features; and I will limit my discussion to a comparison of steam-turbine-driven and motor-driven auxiliaries for power-houses; power in the latter case being obtained from a house turbine.

The principal effect of higher temperature steam is increased expansion. This increased expansion is best taken care of by supporting the turbine at the elevation of the shaft. This modification, together with equipping the turbine with a cast-steel exhaust chamber, seems to overcome the majority of the difficulties in such small turbines. The high-temperature steam comes in contact with only a comparatively small portion of the turbine shell, so it is the effect of the exhaust steam on the main shell that causes the greater expansion. At light loads in small non-con-

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densing units this exhaust steam is highly superheated, as much as 100 degrees F. superheat not being uncommon; so in figuring the effect of temperature changes, a matter of 250 degrees between the turbine cold and in operation has to be taken care of.

Large power-house auxiliaries usually run at speeds varying from about 500 to 900 r.p.m. These speeds are good motor speeds, but are too slow for turbine operation, the result being that when circulating pumps or fans are driven by a turbine, a reduction gear is necessary. This, of course, adds not only considerably to the first expense, but appreciably to the maintenance, after the gear has been in operation for some time. The Springdale plant was originally laid out with the idea that we would put on dual drives; that is, small turbines on one end of our circulating pumps and motors on the other, in order to establish the correct heat balance. At this time we felt that the house turbine was the ideal arrangement, but that the expense would be too great to consider at present. Before the matter was finally closed, we investigated the house turbine system more thoroughly, and found that while the matter of cost afforded no basis for a choice, there was an increased economy of about two per cent. in the station efficiency when using a house turbine instead of steam-driven auxiliaries. The reason for this is that the house turbine will furnish one horsepower for about 18 pounds of steam at its most efficient point, as against roughly twice this amount required by the small steam-turbines when the increased steam consumption at the lower speeds is taken into consideration. The introduction of the generator, switches, and motor, introduces more causes of trouble than if the unit has a direct steam drive. However, as against that, there is the trouble with gaskets, piping, and the additional shut-downs which would be necessitated on account of the reduction gears, in addition to the increased maintenance of the small turbines over the larger unit.

To make the motor-driven auxiliaries as reliable as possible, and to enable an adjustment of the heat balance in the station, all auxiliaries are arranged with two sources of power; one source being the bus supplied by the house generator, and the other source the station transformers connected to the main units.

Practically all turbines of 20,000 kilowatts or over, are sup-

plied with twin circulating, condensate and air pumps, both circulating pumps being required at times of full load or hot water. At times of low load or very cold water, one circulating pump will maintain a good vocuum, as it will supply roughly two-thirds of the amount of water that both pumps will when operating in parallel. There is no unit in a large station to which an interruption will cause more trouble than a circulating pump, if the interruption is such that it will permit of the condenser becoming vapor bound and it is necessary to use steam ejectors to extract the vapor before the water can be raised on the suction of the circulating pumps. To overcome the possibility of trouble from this source, each of the circulating pumps gets its supply of current from a separate bus; so that in case of an interruption to either source of supply, if both circulating pumps are in operation, one will still keep a supply of water flowing through the condenser and prevent it becoming vapor bound. The interruption to the circulating pump, provided that the pump is not self-priming and that valves are not located between the pump and the condenser, permitting of greatly reducing the volume of vapor which has to be extracted before the circulating pump can be started, is very apt to cause an interruption to service of ten times the length that a complete failure of excitation in the station will cause.

In addition to their other advantages, a motor-driven auxiliary station has a much smaller percentage of make-up than a turbine-driven auxiliary station. From the records of some of the best operated plants in the country, this appears to be about two per cent. for a motor-driven auxiliary plant as against about six per cent. for a steam-turbine-driven auxiliary plant. This is particularly important when it is intended to drive boilers at high ratings, as when rates in excess of 250 per cent. of normal rating are contemplated, water of the purest type is required.

The steam-turbine has some natural advantages over the ordinary motor in the matter of automatic regulation; however, there is a motor called the brush-shifting motor, which operates with alternating current and which has characteristics and efficiencies closely approximating the direct-current motor. Its cost is considerably higher; but its efficiency at part loads is very much greater than the ordinary slip-ring motors. It also has the ad-

vantage that its speed can be governed by infinitesimal stages; that, if it is desired to regulate the forced-draft fan very closely, a hydraulic cylinder can be attached either directly or through a pilot motor to the brush-shifting mechanism of the motor, and move it a complete stroke or any fraction thereof, to give the amount of control desired.

One additional advantage of electrically-driven auxiliaries is that in case of an interruption to the station, such auxiliaries in the boiler room will stop at once; whereas, unless automatic control be provided, the steam-turbine-driven auxiliaries will maintain a constant speed until controlled by hand. This may require the addition of a large percentage of make-up if the fans are not shut down.

For starting up a cold station in case of emergency, the small steam-turbine is hard to beat; however, for such purposes, high efficiency can almost always be sacrificed for reliability. In case the station is interconnected with others, power can, of course, be supplied by them direct to the motor-driven auxiliaries.

A station equipped with motor-driven auxiliaries will be much simpler to operate; will have a lower maintenance cost; and will be more efficient—provided power is generated by a house turbine or supplied by the main turbine, and the feed-water heated to 210 degrees by exhaust steam from the house turbine or bled from the intermediate stages of the main unit—than if a similar temperature is reached from steam supplied by small non-condensing steam-turbines.

Mr. Grant D. Bradshaw:* One point in Mr. Rapelye's remarks, as I remember it, is the statement that one of the first applications of steam turbines to be discontinued in favor of motor-driven auxiliary apparatus would be the fans on the forced draft supply to the stokers. There is one feature of that which seems to offset some of the mechanical details; that is, the ability to control the turbine-driven fans in closer conformity to the steam demands, than, so far as I know, has yet been possible with motor-driven apparatus.

The question of proper air supply to the stokers is a question

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of vital importance to plant economy, and in my experience the easiest and most economical way of control is through steam rather than trying to control the motor speeds to get the same effect. It is possible on some of the newer installations that this difficulty in electric control has been overcome, but, if so, I have not heard the details. If anyone has anything to say along that line, I think it would prove very interesting, particularly to the operating man.

Mr. W. J. A. London: Replying to Mr. MacMurchy's statement that the difference in efficiency in small turbines can vary to the extent of 10 or 15 per cent. due to workmanship in the nozzles and buckets, this figure is, I think, excessive. The workmanship and finish on the majority of small turbines is, in general, good; and some tests I carried out some years ago on rough buckets with the edges smoothed off, compared with good finished buckets, showed a difference of less than five per cent.

The comments by Mr. Hodgkinson relative to the designs shown in the paper were particularly gratifying to the author in view of Mr. Hodgkinson's reputation as a turbine engineer.

Mr. Hodgkinson and Mr. Bell have placed before us some strong arguments regarding electrical auxiliaries. From an efficiency standpoint they are unquestionably correct, but from the standpoint of reliability Mr. Bell has himself stated that in order to insure maximum assurance against shut-down with electrical-driven units it is advisable to have two separate sources of power. The interconnection of power stations of course helps out the electrically driven arguments. In isolated stations, however, it is a question of weighing the value of relative efficiency with the conditions and emergencies that are to be reasonably expected—what it actually means to have the boiler feed pumps shut down, for instance, and, with these points in mind, using the best engineering judgment in the choice of equipment. I am indebted to Mr. Bell for the very valuable figures on this subject.

Mr. Rapelye feels that the two-bearing principle advocated in the paper is not feasible with forced-draft equipment. Several of these equipments are in satisfactory operation. I agree, however, with Mr. Rapelye that in this class of work extra care must

be taken in a combination of this kind as so many factors enter in that are not encountered in other types of apparatus. However, if the weights and characteristics of the fan are known and the shaft stresses kept within safe limits there is no reason why this combination should present any difficulties. Referring to Mr. Rapelye's question regarding the distortion due to pipe strain; in the design shown, it will be noticed that movement of the casing due to these pipe strains in no way affects the alignment of the shaft. This is not true with any other design of turbine. In the "Steam Motor" the bearing pedestal is rigidly supported on the base plate. The steam connection is also adjacent to this and before damage can result the exhaust piping must deflect the casing to the full extent of the conservative blade clearance.

WATER-GAS

By A. E. Blake*

Advance copy of a chapter in R. F. Bacon and W. A. Hamor's "American Fuels" to be published by the McGraw-Hill Book Co., 239 W. 39th St., New York. Presented before the Engineers' Society of Western Pennsylvania with the permission of Messrs. Bacon and Hamor, of the Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh.

INTRODUCTION

The possibilities of water-gas as an industrial fuel in this country have been generally overlooked until the present time. It is the object of this paper to present such information and suggestions as may be considered best calculated to interest those who are seeking a relatively cheap but thoroughly adequate gaseous fuel supply. The trend of fuel prices is too well known to everyone, and the industrialist is frequently at his wits end in attempting to cope with the situation.

The re-establishment of competition in manufacture, and its effect upon cost and quality of product, will certainly be factors in the selection of fuels. The use of raw coal, by any means, is becoming more and more generally condemned, especially in technical circles where conservation and thermal efficiency are watchwords.† The use of raw coal as fuel is already prohibited in certain European countries. Were such a restriction to be adopted in America, assuming adequate by-product coking capacity to be provided, not only would the motor-fuel situation be very easy by reason of the benzene and toluene which would be produced, but the use of gas industrially would be very greatly advanced, because of the enormous supply of coke which would be available. This very desirable effect would react upon the petroleum situation and might well release all fuel oil for marine work, for which it is probably better fitted than for any other use.

The writer particularly desires to lay stress upon the natural-gas situation in industrial regions. It should not be an unwelcome demonstration which would show a manufacturer formerly accus-

*Sales Engineer, Surface Combustion Co., Pittsburgh.
†S. M. Darling. (U. S. Bureau of Mines. Technical paper 178, p. 4.)

tomed to rely upon natural gas, but now shortly to be deprived of it, a substitute no more expensive when considered from the efficiency standpoint, and which he can make for his own use, thus becoming free from dependence upon an outside concern for the gas to operate his plant.

Like coal, oil, producer gas, and the electric current, water-gas has limitations of technical and financial character. The writer believes, however, that these limitations are fewer than in the case of any of the other heating agencies with the exception of that most ideal fuel, natural gas.

It is the intention to dwell not only on the subject of water-gas alone, but to call attention to mixtures of it with other gases, best adapted for the varying circumstances existing in industrial plants. It is believed that the two-stage gasification of raw bituminous coal as compared to the one-stage (producer gas) process, cannot fail to interest all those who are considering the use of artificial gas. The two-stage process, to be more fully dealt with below, calls first for the by-product coking of the coal, with consequent recovery of tar and ammonia, and the subsequent generation of water-gas from the coke. Instead of very dirty gas of low calorific power and reaction temperature, the two-stage process yields a clean mixture, nearly three times as rich in heat units, and with a reaction temperature equal to that of natural gas.

It is hoped that the following will appeal especially to those whose production and plant conditions preclude the use of hot, dirty, producer gas; of regenerative furnaces; or of large cumbersome gas mains, which must be frequently cleaned. Such limitations exist in very numerous instances for reasons wholly aside from simple thermal efficiency, and include such items as quality of the product, space and temperature requirements, temperature control, the character and quantity of labor and many others peculiar to a given plant.

Standard practice for generation of water-gas with only the chief advantageous modifications will have mention in this paper. It is desired to lay emphasis upon the fact that we are to consider a process which is capable of many variations; hence the greater possibility of finding a timely and satisfactory answer to the question of plant fuel by those who are facing such problems.

HISTORICAL

In 1780, the action of steam upon incandescent carbon was recorded by Felice Fontana. Enriched water-gas was introduced for illuminating in 1830, by Donovan, but his project was short lived. In 1849, Gillard originated the alternating process of air blow, followed by a steam blow. Patents were granted J. & T. N. Kirkham in 1854, however, for doing the same thing. For the period between 1856 and 1865, the town of Narbonne, France, was lighted by means of water-gas and mantles of platinum wire.

What may be termed the modern history of water-gas begins in America. In 1873, a water-gas plant was placed in successful operation at Phoenixville, Pa. This development was brought about by J. S. C. Lowe, Strong, and Tessie du Montay. Lowe and Dwight installed a water-gas plant at Essen, Germany, in 1882. A Lowe plant was built in England, at Leeds Forge, in 1888. Water-gas was made in Pittsburgh from 1892 until 1919, and formed an important part of the output of artificial gas used chiefly for lighting purposes.

About 1898, C. Dellwick and E. Fleischer modified the process by which the gases formed during the air blow contained practically all of their carbon as the monoxid, according to the reaction $2C + O_2 = 2CO$, by increasing the force of the air blast and at the same time cutting down the thickness of the fuel bed in the generator. This enabled them to produce more heat in the working bed by promoting complete combustion according to the reaction $C + O_2 = CO_2$. These steps enabled them to reduce the customary length of air blow from 8 or 10 minutes to 1.5 or 2 minutes. They also adopted the practice of reversing the direction of steam passage through the bed in order to increase the efficiency of the process. They employed steam at pressures from 150 to 160 pounds per square inch, utilizing sensible heat in the gases leaving the generator, to superheat the steam.*

*To show the alertness of the engineering profession in the early days of the gas industry, the following facts may prove interesting:

The Pittsburgh Gas Works Company was formed in April, 1835, by the city treasurer, and the plant was subsequently built and operated by the city. The company was authorized "to construct a suitable works for the manufacture of carbureted hydrogen gas from bituminous coal, for the purpose of public and private illumination." Three Lowe, one-way, seven-foot-diameter gas machines, with a daily capacity of 1,200,000 cubic feet of carbureted water-gas constituted the recently dismantled plant on Second Avenue, Pittsburgh.

THEORY OF WATER-GAS GENERATION

The simplest conception of a water-gas generator comprises a bed of granular carbon supported upon a grate in a retort.

The process starts by ignition of the carbon, and the blowing of air up through it, until the granules become incandescent by oxidation of some appreciable portion of them. The gases leaving the retort during the air blow consist of CO and N_2.

At the proper degree of incandescence, blowing of air is discontinued and steam is introduced in its place. The steam is decomposed by the carbon to yield equal volumes of carbon monoxid and hydrogen. Twelve parts of carbon react with 18 parts of steam by weight, yielding 28 parts of monoxid and two parts of hydrogen by weight. While the passage of air causes a reaction which liberates heat to the remaining carbon, the passage of steam has the opposite effect, resulting in rapid cooling of the bed and necessitating the passage of more air. The product of the air blow may be used as fuel to generate the steam required. The product of the steam blow is water-gas.

The following thermochemical reactions will illustrate the foregoing, and they are written in the order in which they occur:

Air Blow

(1) $2C + O_2 = 2CO$ + 58,800 calories, or 29,400 calories per gram atom of carbon.

(2) $2CO + O_2 = 2CO_2$ + 136,400 calories, or 68,200 calories per gram atom of carbon.

(3) $CO_2 + C = 2CO$ — 38,800 calories per gram atom of solid carbon.

Hence the net heat liberated equals 68,200 — 38,800 or 29,400 calories per gram atom of carbon oxidized to CO.

Steam Blow

(4) $C + H_2O = H_2 + CO$ — 28,800 calories per gram atom of carbon.

This reaction occurs while the carbon is at a temperature greater than 1000 degrees C. (1832 degrees F.)

(5) $C + 2H_2O = 2H_2 + CO_2$ — 18,800 calories per gram atom of carbon.

Reaction (5) begins to displace reaction (4) at about 1000 degrees C., and increases with decrease in temperature. Below 625 degrees C. no appreciable reaction takes place. So long as there remains a zone above the cooled region which is still about 800

degrees C.,* all except about 9.3 per cent. of the carbon dioxid is reduced to carbon monoxid, according to equation (3). This is also an endothermic reaction, and the steam blow must cease promptly when reaction (5) sets in, to prevent waste of steam and the presence of CO_2 and water vapor in the product.

It is evident that for each gram atom of carbon entering water-gas, 28,800 calories must be supplied to enable reaction (4) to take place. For each gram atom of carbon entering producer gas 29,400 calories are made available as sensible heat in the generator. It is also true that the gaseous product of the air blow contains a potential heat of 68,200 calories per gram atom of carbon content and it is generally found best to utilize it for steam raising along with the sensible heat of the gases.

The theoretical composition of the water-gas by volume is 50 per cent. CO and 50 per cent H_2. The calorific value would be 324 B.t.u. gross, per cubic foot at 60 degrees F. and standard barometer. Carried out in accordance with the foregoing, and assuming there are no losses of sensible heat, only enough carbon would need to be burned in the generator to supply the heat requirements of reaction (4) and furnish an adequate potential source of heat for steam raising.

The evaporation of a gram molecule of water from and at 20 degrees C. requires 10,800 calories. This added to the absorbed heat of reaction, 28,800, gives a total heat requirement of 39,600 calories.

PROCESS OF MANUFACTURE

The raw materials of water-gas manufacture are steam, supplied at pressures generally greater than five pounds per square inch; and some available form of carbon, such as coke, anthracite, petroleum coke, charcoal, or a bituminous coal of a non-coking character, as for example, Southern Illinois coal. Air must be supplied for intermittent use at about 1.5 pounds pressure per square inch.

Fig. 1 illustrates a modern water-gas set in simple form.

Fig. 2 illustrates such a set in cross-section.

*Comptes rendus hebdomadaires des seances de l'Acadamie des Sciences, 1900, v. 130, pp. 132–134; v. 131, pp. 1204–1206.

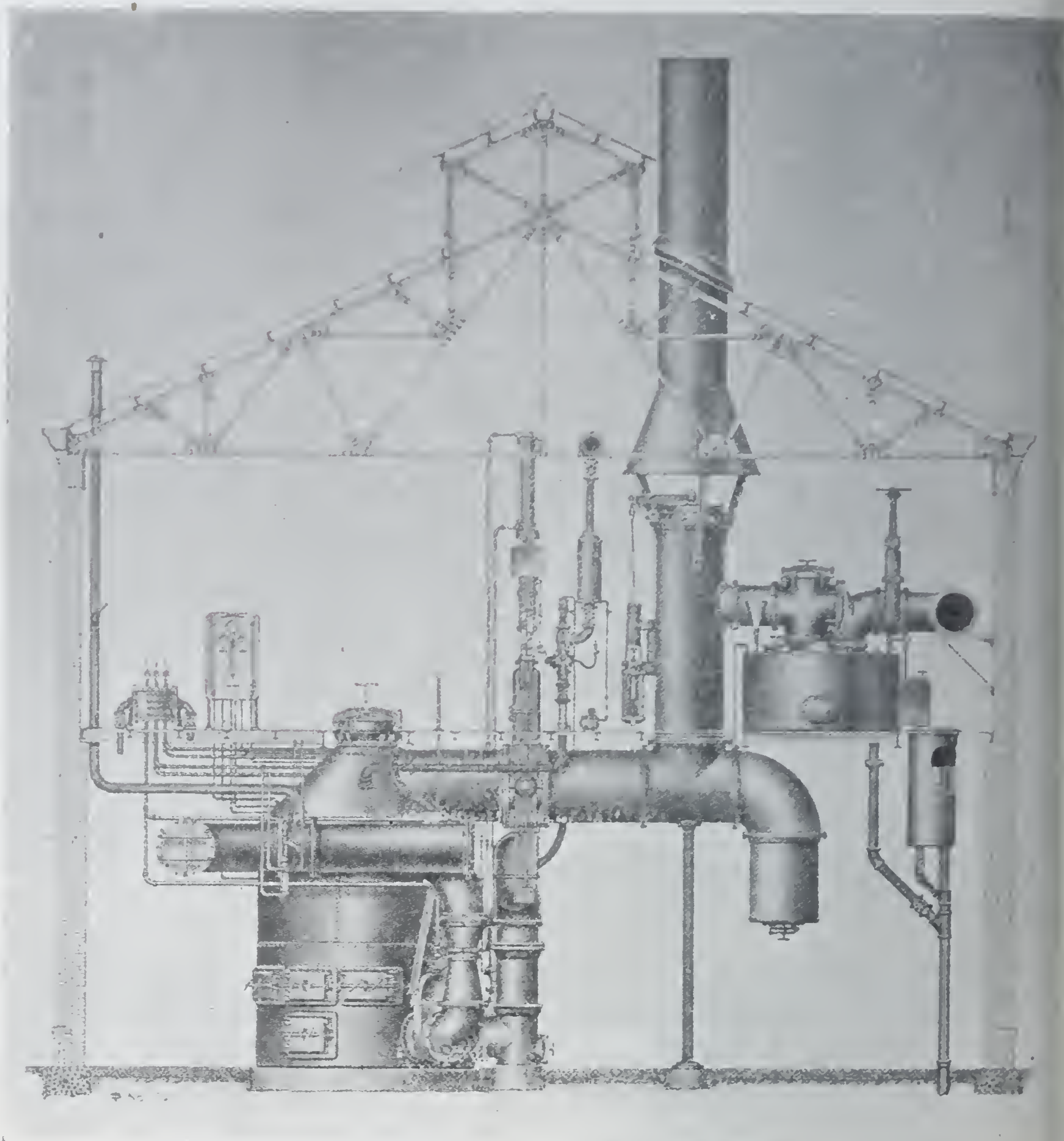

Fig. 1. Water-Gas Generator.

The principal features to which attention is called in these figures are the generator; its shell; insulated brick lining; grate; clinkering and clean-out doors; charging port; upper and lower exits for gas (the lower takes off water-gas only); upper steam inlet; lower steam inlet (shown faintly); air inlet (the venturi); hydraulic control station (on charging floor to left of generator); valves, and their hydraulically operated mechanism, for air, steam, water-gas, producer gas, and stack control; and water seal. If one assumes that the external diameter of the generator is 11 feet, this being a common size, he will be able to gain a good idea

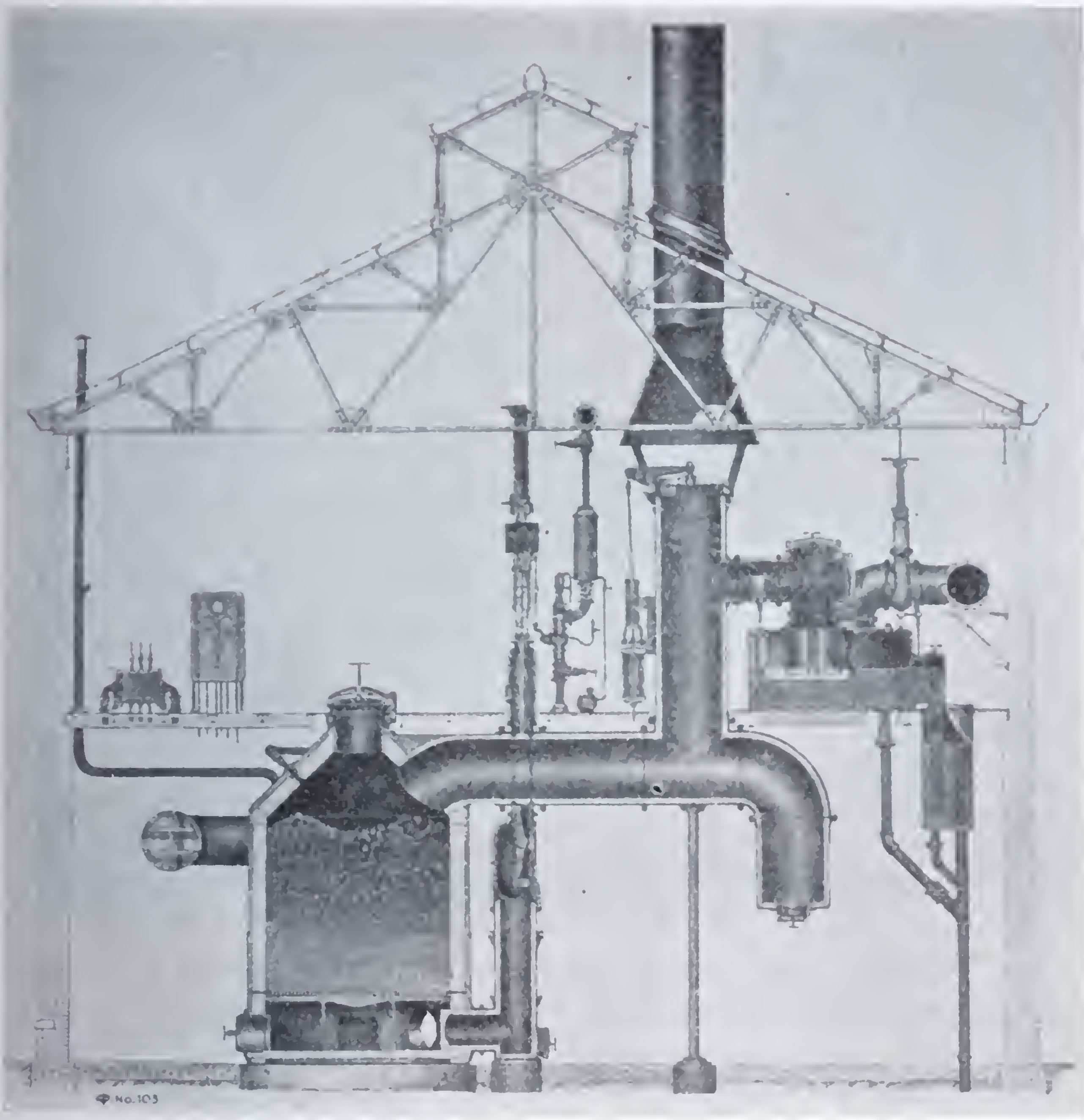

Fig. 2. Water-Gas Generator. Sectional View.

of the other principal dimensions, including those of the building.

An 11-foot set is rated at from 100,000 to 150,000 cubic feet per hour. On the basis of thermal values, this would be the equivalent of from 33,000 to 50,000 cubic feet of natural gas of 1000 B.t.u.

The cycle of the water-gas process varies slightly with different installations and from such considerations as kind of fuel, quality of product, and preference of those in charge. A representative cycle might consist of two minutes for blowing air and four minutes for blowing steam. It is also customary to blow steam upward through the grate for half of the steaming period,

and downward from above the fuel for the remainder of the period.

It is possible, with the use of quite a shallow fuel bed, to blow air rapidly enough to produce oxidation products which are mainly CO_2 ($C + O_2 = CO_2 + 97{,}600$ calories). This enables a very rapid heating of the fuel, as mentioned before, and enables the steam blow to follow much sooner than if CO were the product of the air blow, when 29,400 calories are freed per gram atom of carbon oxidized. Such an apparatus can well be used for supplying the daily requirements of an industrial plant, where 8 or 10 hours of service are required. Since it becomes necessary to "clinker" or clean the grate bars once in each 8 or 10 hours, the time limitation is thus explained. A small gas-holder is required for such service, although it need be only such as to contain the plant requirements for a brief period. A stand-by set can be installed if considered advisable from the standpoint of avoiding losses from occasional shut-down.

For continuous twenty-four hour service, the best practice at the present time calls for the utilization of the sensible heat of the gases coming from the generator, and of the heat of combustion of all carbon monoxid generated during the air blow. Fig. 3 shows, in addition to the generator and accessories already named, a combustion chamber under the main stack; a waste-heat boiler and steam drum; boiler stack with stack valve; air blower; fuel bin; fuel car, and ash car. For such an installation, there would be one stand-by generator set, and one boiler can be used for either operating set or stand-by set. (See Fig. 6.)

Sufficient steam can be generated in the boiler to supply the needs of the process, including the requirements for power, etc.

Water-gas sets are now operated with automatic controls, which automatically operate the set valves at the proper time. The automatic control is a most important feature of any water-gas installation. It is an insurance against ignorance and carelessness, and it does the work which would otherwise be required of a skilled operator. In addition, it enables the apparatus to be operated in shorter cycles, thus saving fuel and increasing capacity.

The control is afforded by a small motor of 1/10 horse-power, and consists of a gear train, cams and pilot valves, inclosed

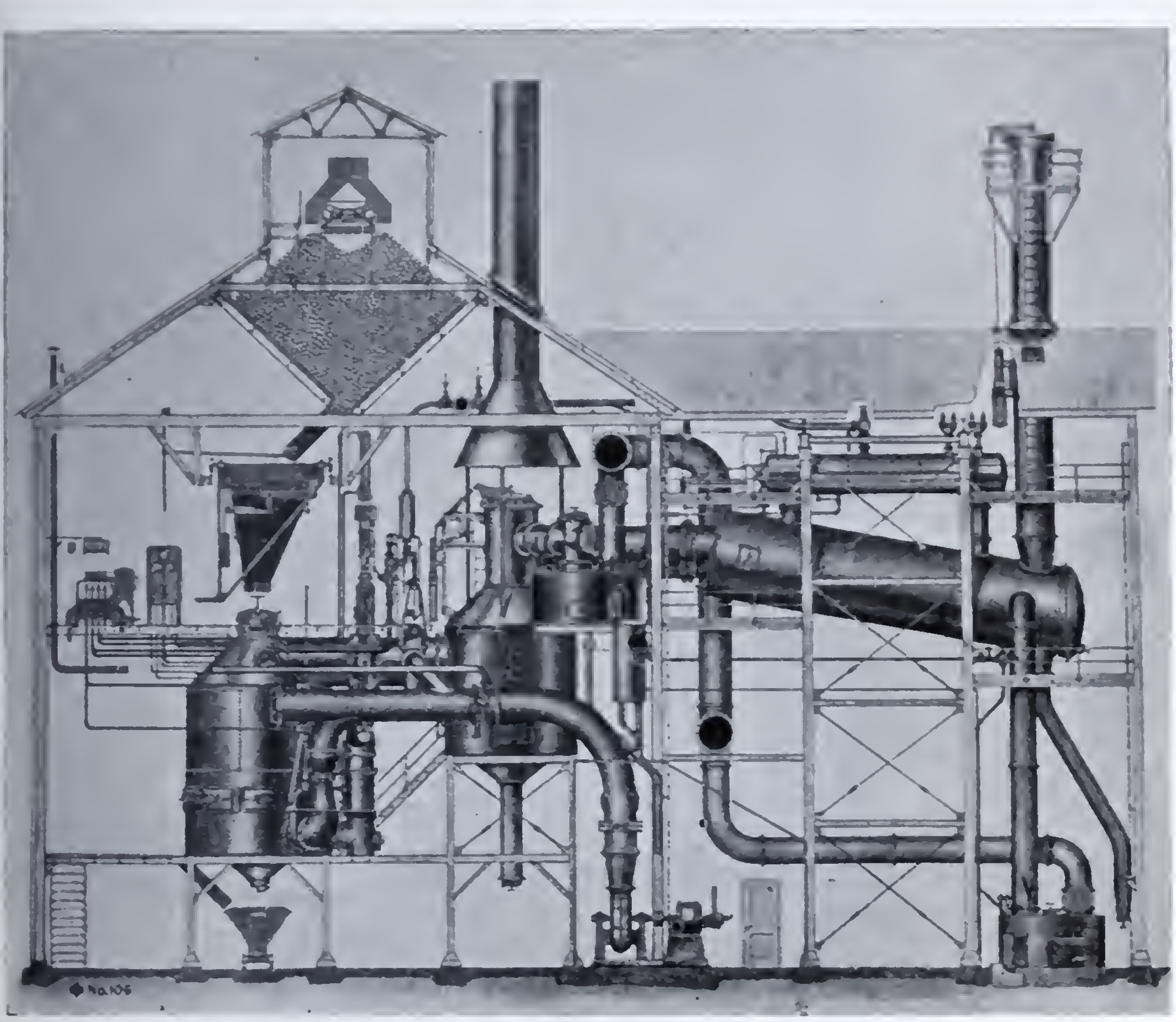

Fig. 3. Water-Gas Generator with Combustion Chamber, Waste-Heat Boiler, and Accessories.

in a case outside of which are the dials, run counter, illuminated signal box, and other accessories for setting the apparatus to follow the desired cycle. A glance at the signal box serves to tell precisely what stage of the cycle is taking place at any time. There is an electric alarm and provision for instant shut-down. Every valve and mechanism to be governed in the cycle of operations is connected with the controller by a hydraulic line by means of which hydraulic pistons upon the valves are operated. It is due to this development that a modern gas plant consisting of several sets can be operated by one man who attends to coaling and cleaning fires and has general charge of the apparatus.

Fig. 4 and 5 illustrate a controlling station such as has been described.

Fig. 6 shows a typical lay-out of a blue-gas plant with waste-heat boiler with a holder for relief and storage.

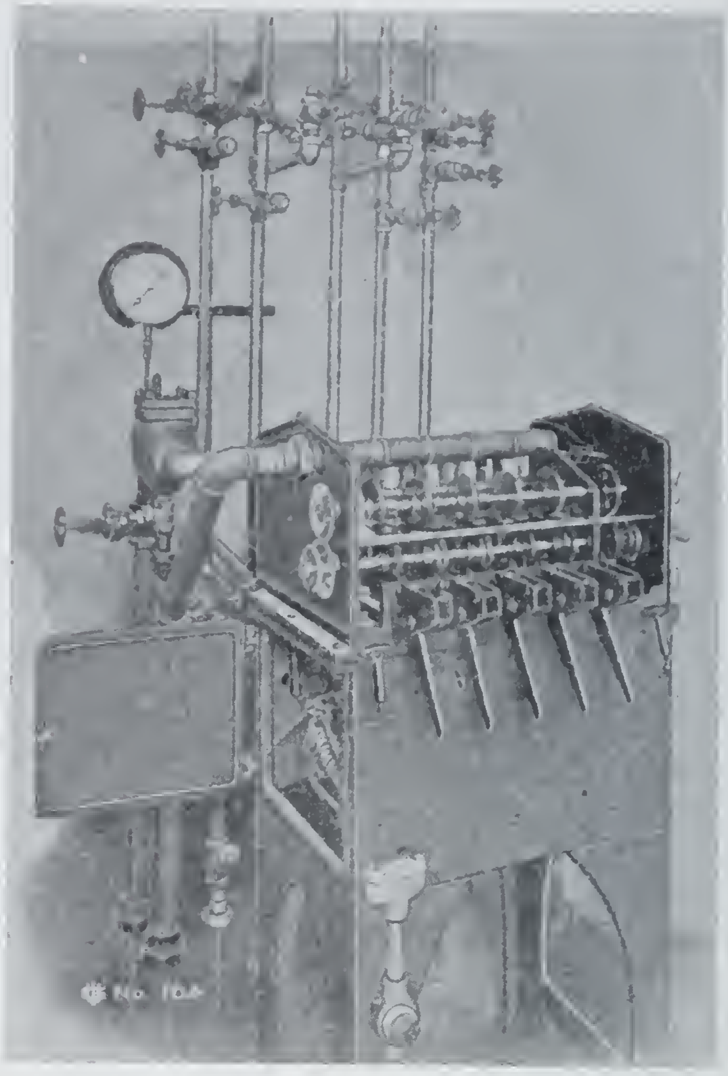

Fig. 4. Automatic Control Station for Water-Gas Plant.

PROPERTIES AND USES OF WATER-GAS

As has been shown, the theoretical water-gas would be 50 per cent. hydrogen and 50 per cent. carbon monoxid, by volume. Hence one cubic foot would have a calorific value of 324 B.t.u. gross, at 60 degrees F., or 316.5 B.t.u. net. The heat content of the average "make" of water-gas is close to 300 B.t.u. (net) per cubic foot at 60 degrees F.

Two specimen analyses are given below:

CO	43.5
H_2	47.3
CH_4	0.7
CO_2	3.5
O_2	0.6
N_2	4.4
	100.0

B.t.u. per cubic foot = 302 at 60 degrees F. Specific gravity 0.559 at 60 degrees F.*

*Furnished by Mr. Charles J. O'Donnell of the U. G. I. Contracting Co.

CO	39.1	
H_2	49.3	
CH_4	0.8	
CO_2	6.8	
O_2	0.3	
N_2	3.7	(difference)
	100.0	

B.t.u. per cubic foot = 295 + 2 per cent.*

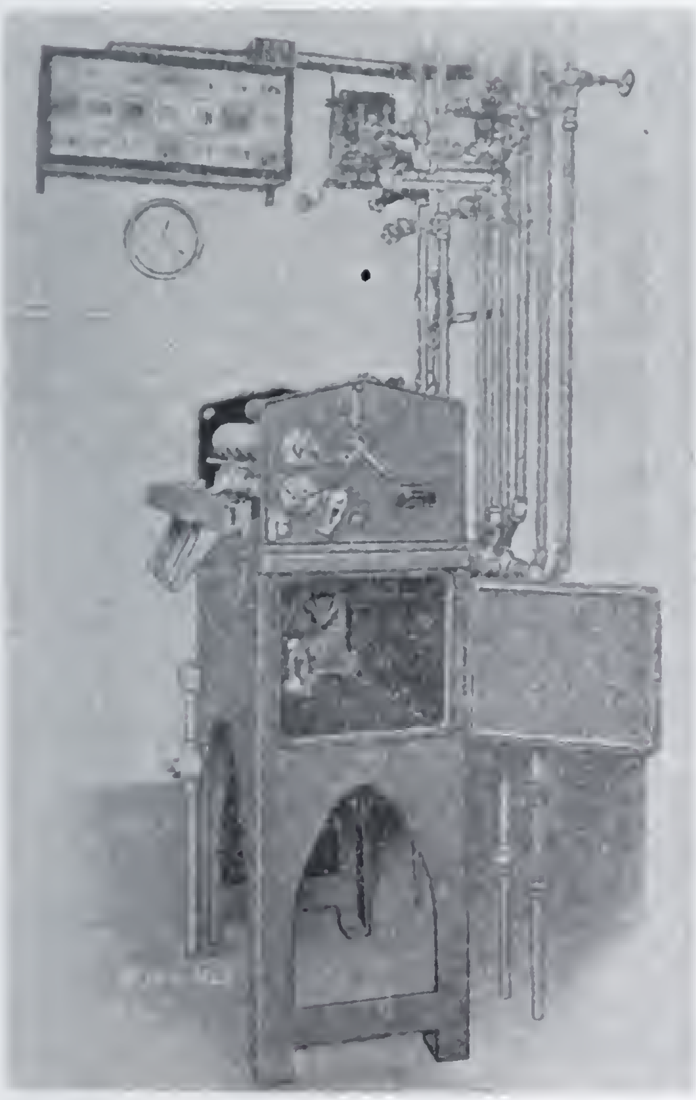

Fig. 5. Automatic Control Station for Water-Gas Plant, Showing Indicator (upper left).

*Average of 15 samples taken at 20 minute intervals. Supplied through the kindness of Mr. A. J. Huston, Hyatt Roller Bearings Division of General Motors Co.

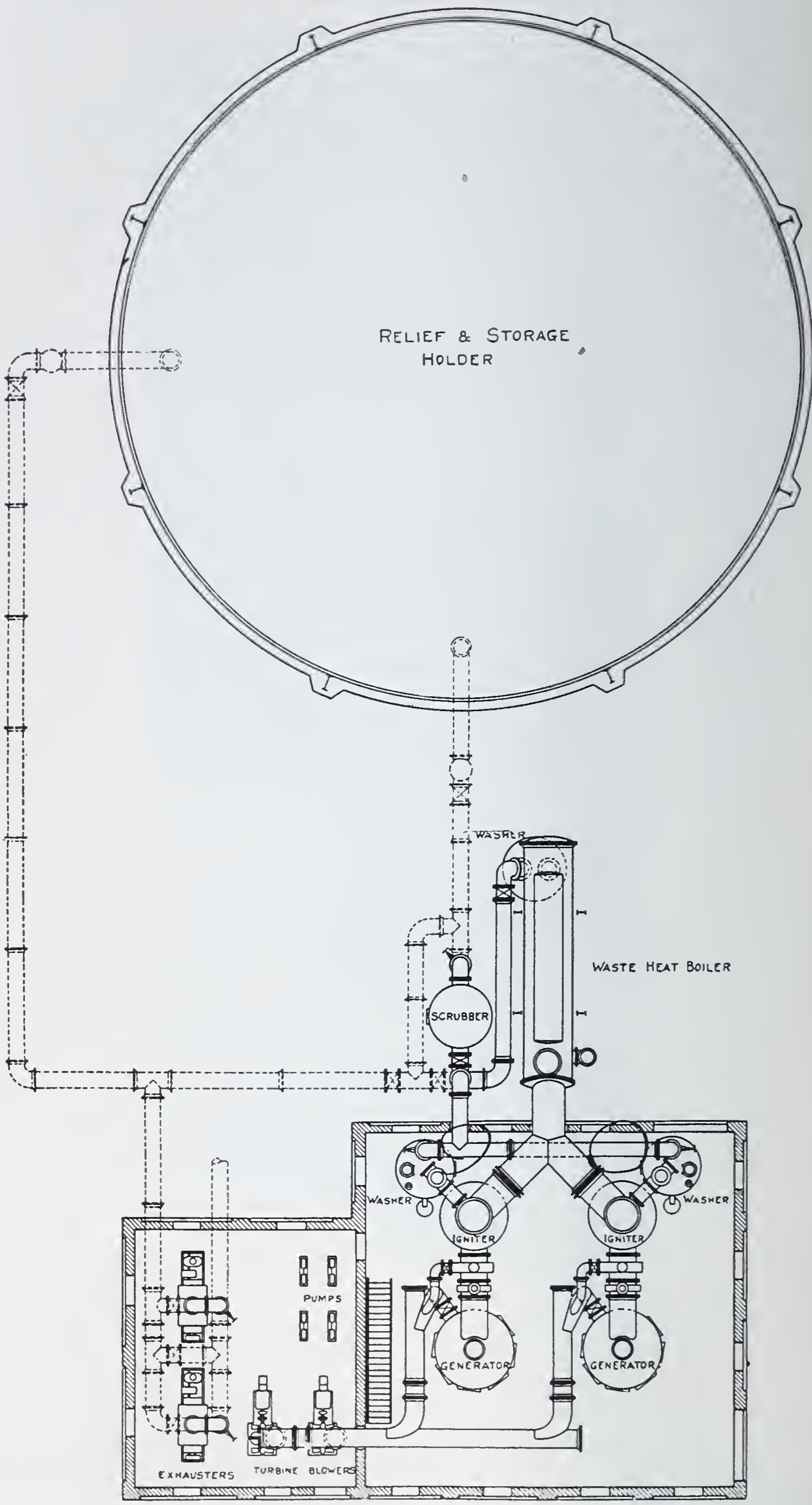

Fig. 6. Lay-Out of Water-Gas Plant with Twin Generators, Waste-Heat Boiler, Holder, and Accessories.

One net ton of good coke or anthracite will yield about 52,500 cubic feet of water-gas, or a return in gas fuel of about 8000 B.t.u. per pound of coke. Assuming the coke contains 10 per cent. ash and has a heat content of 13,140 B.t.u. per pound, the efficiency of the process is about 61 per cent.

Because of its carbon monoxid content, water-gas burns with a blue flame, hence the terms "blue gas" or "blue water-gas," frequently applied to it. The carbon monoxid is also responsible for the fact that the gas is poisonous, as is also the case with producer gas and blast-furnace gas. Measures can be taken in the process of making to insure that the gas will have sufficient odor to serve as a warning in case of any leakage.

On account of the character of fuel used, water-gas is very easily cleaned, being free from tar, and carrying only dust which is easily scrubbed out. This is a point in contrast to producer gas from bituminous coal. Water-gas is frequently compressed and piped for many miles at high pressure, without the slightest tendency to clog the mains. Thus a very small main can carry great quantities of heat units, compared to the quantities to be sent through a cumbersome and expensive brick-lined main for tarry producer gas. Freedom from tar, and the relative density of the water-gas make it admirably adapted to the well known jet-entraining apparatus for utilizing the energy of a gas-jet to entrain and mix the proper amount of air for theoretically perfect combustion. Hence only gas piping is needed in a plant using water-gas, and air blowers, air piping and stacks are made unnecessary.

The theoretical ratio of gas to air for quantitative combustion is about 1 to 2.1. Hence, one cubic foot of the gas with a calorific value of 300 B.t.u. and two cubic feet of air, will form three cubic feet of a mixture which has a heat content of 100 B.t.u. per cubic foot. One cubic foot of 1200 B.t.u. natural gas requiring 11 cubic feet of air for perfect combustion will form a mixture with a calorific value of 100 B.t.u. per cubic foot. One cubic foot of 150 B.t.u. producer gas, however, requiring 1.3 cubic feet of air per cubic foot, yields a mixture containing only 65 B.t.u. per cubic foot. Approximately 60 per cent. of producer gas is inactive nitrogen, so that there is a vast difference in the rates of combustion of water-gas and producer gas. The theoret-

ical reaction temperature of average water-gas not carrying sensible heat, is generally placed at about 3500 degrees F.; whereas that for producer gas is usually given as from 2400 to 2900 degrees F.

It is impossible to produce smoke when firing with water-gas—a fact of importance to those who must observe smoke ordinaces. Furthermore, there will be produced only the chemiluminescent blue flame, or no flame at all, when using the gas as fuel. This would be a considerable hindrance to its use in the open-hearth, or in regenerative glass tanks, as such installations are designed at present. Since producer gas is well adapted for practically all regenerative work, which affords opportunity for utilizing sensible heat (tarry impurities and all) there is shown to be a clear line of demarcation between the two gases as regards their special fields. For many classes of welding, water-gas is ideal, whereas producer gas is generally useless for that purpose. It is quite common for producer gas supplies to fluctuate materially in calorific value, making it difficult or impossible to secure close temperature control. The heat content of a water-gas supply can be maintained very constant, thus well adapting it to such work as annealing, hardening and tempering of steel and other alloys, galvanizing, tinning, etc., as well as for high temperature work, where regeneration is impracticable. One special and time-honored use for water-gas is for welding steel tubing and tanks of large size. From the standpoint of fitness, there is no heating operation now carried on with natural gas which cannot be conducted with equal or even greater facility with water-gas.

MODIFICATIONS OF WATER-GAS AND THEIR USES

Carbureted Water-Gas. The commonest, and before the World War, probably the cheapest artificial gas for domestic use was carbureted water-gas, or the blue water-gas mixed with cracking products of petroleum. The high cost of oil at present is proving a very great handicap to its use for this purpose.

Fig. 7 shows a water-gas plant minus a waste-heat boiler, but with the additional appurtenances for carburation, consisting principally of a checker chamber of bricks kept hot by the sensible heat of the water-gas passing through and serving to crack

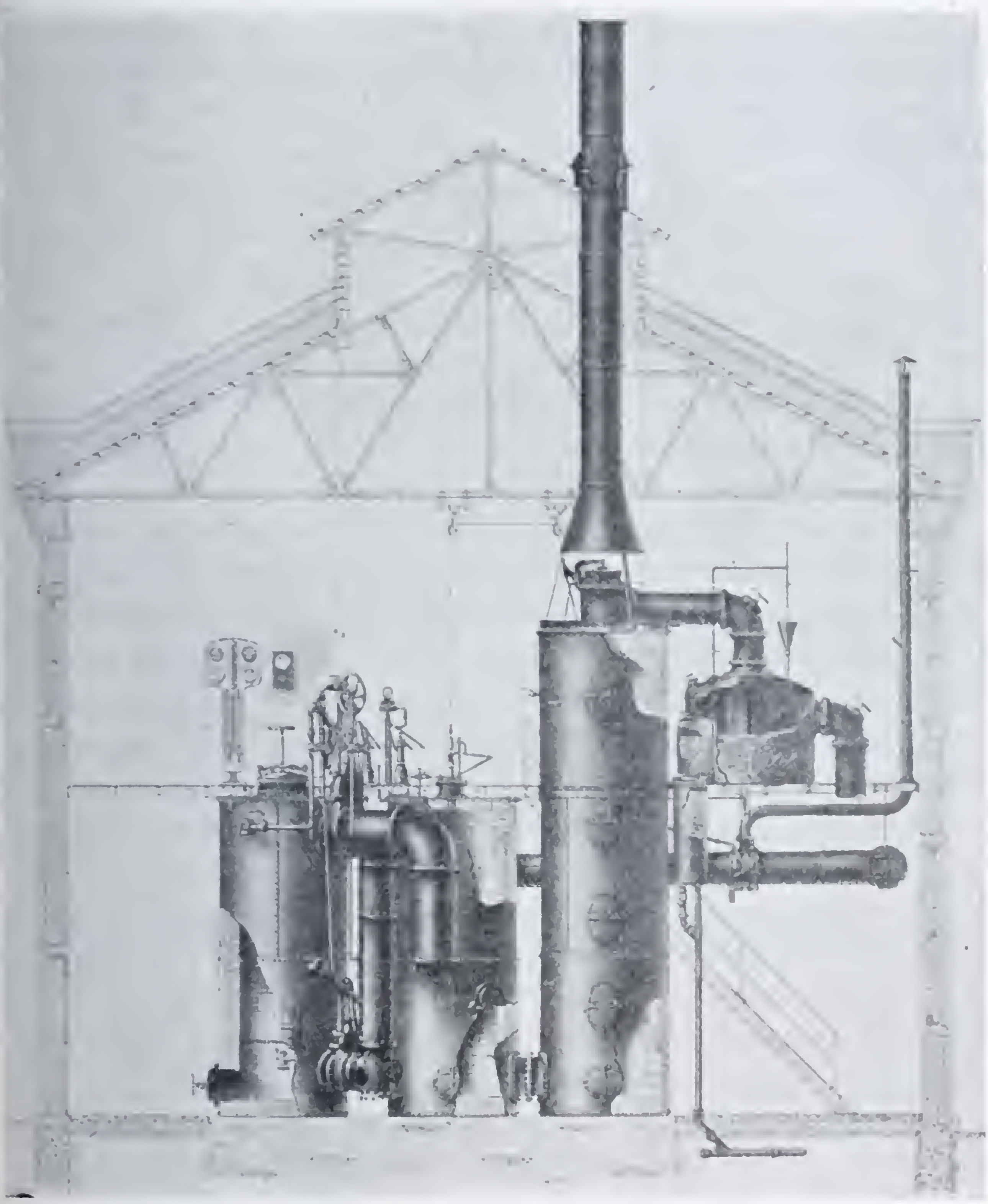

Fig. 7. Standard Double Superheater Lowe Apparatus for Making Carbureted Water-Gas.

the oil which is sprayed toward them; also a superheater of checker brick in which oil cracking products are further heated to form permanent gases. The superheater is kept hot by intermittent combustion of the producer or "air" gas from the generator. Formerly, topped Pennsylvania crude oil was used, but Gulf oil, from which gasoline and kerosene have been removed is used at the present time.

The addition of oil gas to water-gas is entirely unnecessary from the standpoint of domestic heating; but, unfortunately, the earliest use for artificial gas in cities was that of lighting. Welsbach mantles had not appeared, and the fish-tail jet was the commonest burner in use. The added hydrocarbons furnish the required luminosity to water-gas flame, thus enabling it to fulfill legal requirements as regards candle-power and to meet those pertaining to calorific power. The reader will bear in mind, however, that the town of Narbonne, France, was lighted for nine years by blue water-gas and platinum mantles. Had the Welsbach mantle been available at that time, it is quite likely that few of the laws in regard to candle-power and calorific value would have been enacted; or, at least, they would be far more tolerant. As it is, the tendency is for fewer and less severe restrictions.* Blue water-gas is ideal for the Welsbach mantle, but not for the practically extinct fish-tail burner. The heat units added by way of cracking products are by far the most costly, at the present prices of oil; hence, if the matter were rightly and generally understood, it seems as though the present hampering restrictions would quickly disappear along with the present enormous demand for gas oil.

The following are specimen analyses of carbureted water-gas:

Illuminants	10.7	12.9	12.82
CO	33.4	28.1	28.26
H_2	38.1	21.8	37.20
CH_4	7.6	30.7	18.88
C_2H_6	2.4	......	....
CO_2	3.3	3.8	0.14
O_2	0.7	0.5	....
N_2	3.8	2.2	2.70
	100.0	100.0	100.00
Candle power	20.2	......	22.0
B.t.u. per cubic foot	602	659.6	....
†Specific gravity	0.676	‡	0.5825§

*F. W. Steere. Trend of progress in gas supply. (In Gas Age, v. 45, pp. 389–390.)

†Mr. Chas. J. O'Donnell.

‡C. E. Lucke. Engineering thermodynamics. 1912. New York: McGraw.

§W. A. Bone. Coal and its scientific uses. 1918. London: Longmans.

In addition to the cost of carbureted water-gas, precautions are always necessary to prevent it from reaching a temperature below that to which it is reduced in the scrubbing process, in order to prevent condensation of the relatively heavy vapors the loss of which seriously impairs the candle-power, while tars are formed which clog the pipes.

Combination Coal-Gas and Water-Gas. Because of the very attractive possibilities presented, much attention has been directed of late to the possibilities of mixed water-gas and coke-oven or retort coal-gas.

The by-product coke-oven is a natural adjunct to any steel plant which operates blast-furnaces, its chief function being that of producing the necessary metallurgical grade of coke. Blast-furnace operators know, however, that much of the coke charged to a blast-furnace is unsuitable because of its small size. The screenings commonly known as "breeze" are regularly discarded; but small coke up to two-inch mesh is known to have a pronounced effect in hindering the passage of gases through the furnace burden, and its omission results in appreciably larger production of metal. This small size coke is well suited as a fuel for water-gas generation, and a valuable supply of high-grade gas fuel is made available, the uses for which in a steel plant are too well known to mention. The water-gas can be mixed with the coke-oven gas if desired. Since water-gas is well adapted to heating coke-ovens, it is possible to avoid the use of lean coke-oven gas which has from 400 to 500 B.t.u. per cubic foot, thus making it available for the various steel plant furnace operations.

The total gasification of coal can be accomplished in two ways. One is by use of the producer, with which we are all familiar. The other is a two-stage process, involving coal carbonizing apparatus and water-gas generators. It should pay us to consider the latter case in some detail.

One net ton of bituminous coal will yield about 1400 pounds of coke, 6 pounds of ammonia (NH_3), 14 gallons of tar, and

about 11,000 cubic feet of 570 B.t.u. coal-gas, when a portion of the coke (about 350 pounds per ton) consisting of the small coke and breeze, is used to form producer gas for coking.

The 1050 pounds of coke will produce about 27,600 cubic feet of 300 B.t.u. water-gas. These two yields of gas can be used separately, if desired, or they can be sent to the same holder, where will be formed a mixture each cubic foot of which will have a calorific value of 375 B.t.u. This mixed product will burn with a slightly luminous flame, though that fact is of small importance in the majority of cases, owing to the superior advantages now realized by the use of modern methods of combustion. The value of by-products recovered is sufficient to meet operating costs.

There are available excellent types of coking units with such capacities as to meet the demands for moderate amounts of gas fuel. Some of these units are of the vertical, self-discharging type, fired by producer gas and reducing the operating costs for labor to a minimum.*

A combination gas plant with a total daily capacity of about 30 tons of coal would represent a minimum size for such an installation. This compares very favorably with the common powdered coal plants of which the minimum efficient capacity is about 80 tons per day.†

Many readers will call to mind the almost obsolete horizontal retort coke plants which supplied the "coal-gas" in our cities twenty years ago and which are still quite numerous. The coke was usually rather difficult to dispose of, and with development of the water-gas process, this coke came to be used to increase further the gas output of such plants. Such was the practice in Pittsburgh, even, up until 1919. Mention of the foregoing is due, in order to show that there is nothing new in the matter of mixed

*W. V. Turner. (In Gas Record, 1918, v. 14, No. 7.)

†John E. Muhlfeld. Powdered coal. 1920. (In Proceedings of the Engineers' Society of Western Pennsylvania, v. 36, pp. 243-273.)

water-gas and coal-gas. The vastly superior modern apparatus for making such mixtures deserves the attention of every fuel engineer, however. Allusion has been made to the possibility of legislation against the use of raw coal as a fuel. It would seem that the combination coal- and water-gas plant is due to have a bright future in case such legislation is ever enacted.
cedure. Water-gas is being added to natural-gas supplies in some regions, especially in cold weather when the demand for fuel is great.

There is no limit to the variety of mixtures which can be had by the use of water-gas, coke-oven gas, producer gas, and other gas fuels. Plant conditions will serve to determine the procedure.

COSTS

Many interesting demonstrations have been made in the past few years as to the comparative cost of water-gas, and other gas fuels. For instance, those in charge of the huge gun and shell shop project for Neville Island, in 1918, learned that the cost of a million B.t.u. delivered as water-gas would have been only about 1.5 cents greater than the cost of the same quantity of heat delivered as raw producer gas. Water-gas was decided upon as the fuel to be used for heat treatment, annealing, shell nosing, and all other proposed heating operations, excepting open-hearth firing.

The writer has knowledge of a proposal by a leading gas engineering concern to a glass company in the Pittsburgh District for the construction of a combination coke-retort, water-gas plant to furnish the heating equivalent of 2,500,000 cubic feet of natural gas per day, at an overall cost of $0.362 per million B.t.u. This was in June, 1919.

Table I shows the cost of water-gas alone, at various costs for coke.*

*Courtesy of the U. G. I. Contracting Co.

TABLE I

COST OF MAKING BLUE WATER-GAS

No. of 11' sets in plant		3		4		5		6	
Thousand cu. ft. per day		5,000		7,500		10,000		12,500	
Working capacity of plant, 1 set idle, per year		1,600,000		2,400,000		3,200,000		4,000,000	
Working capacity per day		1,500		2,250		3,000		3,750	
Million B.t.u. per year		480,000		720,000		960,000		1,200,000	
Total estimated cost of plant		$500,000		$620,000		$750,000		$875,000	
Investment cost at 12% total		$60,000		$74,000		$90,000		$105,000	
		per 1000 cu. ft.	million B.t.u.	per 1000	million B.t.u.	per 1000	million B.t.u.	per 1000	million B.t.u.
		.0375	.125	.03	.103	.028	.089	.026	.088
Labor cost..........		.0275	.0915	.0271	.09	.0247	.082	.022	.073
Repair cost.........		.0075	.025	.0075	.025	.0075	.025	.0075	.025
Supplies, power, miscellaneous......		.005	.016	.005	.016	.005	.016	.005	.016
Generator fuel.	4.00	.08	.266	.08	.266	.08	.266	.08	.266
Cost of coke	5.00	.10	.333	.10	.333	.10	.333	.10	.333
	6.00	.12	.400	.12	.400	.12	.400	.12	.400
	7.00	.14	.466	.14	.466	.14	.466	.14	.466
	8.00	.16	.533	.16	.533	.16	.533	.16	.533
	9.00	.18	.600	.18	.600	.18	.600	.18	.600
	10.00	.20	.667	.20	.667	.20	.667	.20	.667
Holder cost	4.00	.12	.404	.12	.398	.117	.390	.115	.371
exclusive of	5.00	.14	.472	.14	.465	.137	.457	.135	.448
investment	6.00	.16	.538	.16	.532	.157	.524	.155	.515
	7.00	.18	.606	.18	.598	.177	.590	.175	.580
	8.00	.20	.674	.20	.665	.197	.656	.195	.648
	9.00	.22	.738	.22	.733	.217	.724	.215	.716
	10.00	.24	.808	.24	.800	.237	.790	.235	.783
Total cost of	4.00	.158	.529	.15	.500	.145	.479	.141	.470
gas including	5.00	.178	.597	.17	.567	.165	.546	.161	.536
12% on invest-	6.00	.198	.663	.19	.635	.185	.613	.181	.603
ment	7.00	.218	.731	.21	.700	.205	.679	.201	.670
	8.00	.238	.799	.23	.766	.225	.746	.221	.736
	9.00	.258	.860	.25	.832	.245	.816	.241	.803
	10.00	.278	.927	.27	.900	.265	.884	.261	.870

Fig. 8 shows graphically the cost of water-gas, coke-retort gas, and the resulting mixture from the two-stage process referred to in the foregoing, at any stated price for coal.†

†Gas Age, v. 45, p. 381.

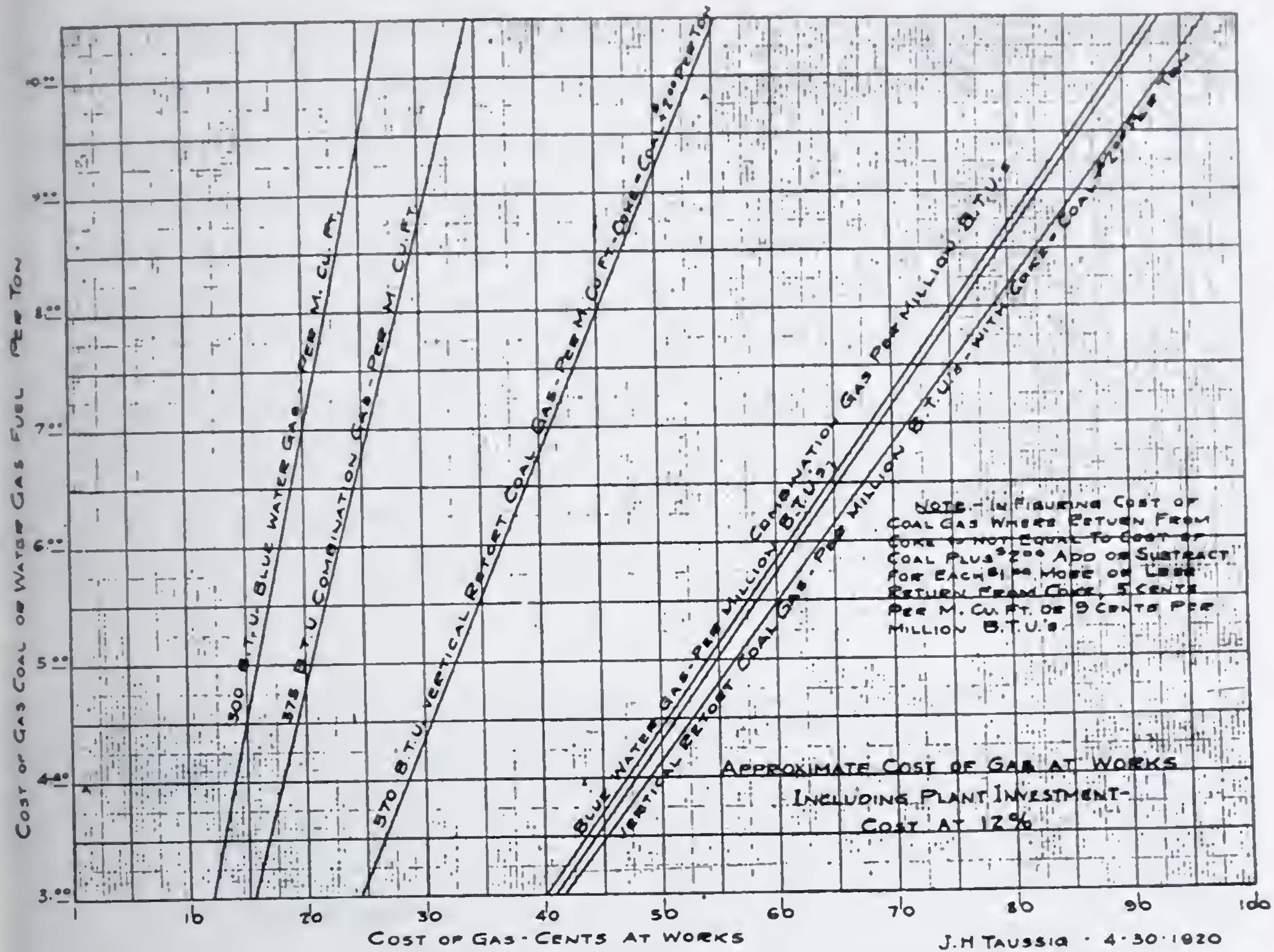

Fig. 8. Cost Curves for Water-Gas, Coke Retort Gas, and Mixture Resulting from Two-Stage Gasification of Coal.

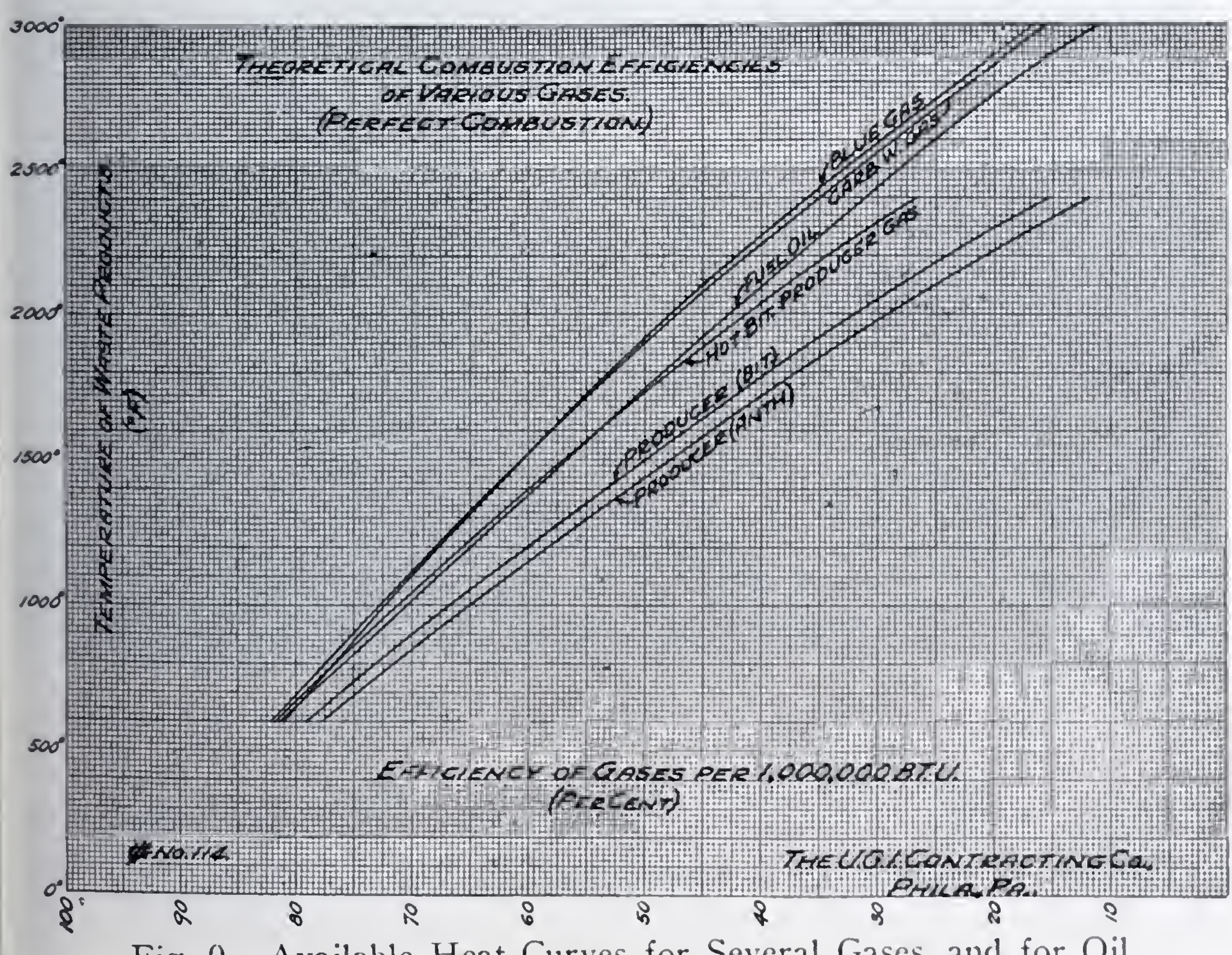

Fig. 9. Available Heat Curves for Several Gases, and for Oil.

Fig. 9 shows a set of curves which have been prepared to show the comparative heating efficiencies of six common fuels. These are water-gas; carbureted water-gas; hot bituminous producer gas; clean, cold bituminous producer gas; clean, cold anthracite producer gas; and fuel oil. The curves have been plotted with reference to the theoretical percentage of a million heat units which a furnace can retain, as compared to that carried away by the flue-gases. In all cases, perfect combustion is assumed and, fortunately, perfect combustion is no longer difficult to maintain when the fuel is gaseous. Where inefficient means of firing are employed, it is probable that the relation of the curves shown would be little changed.

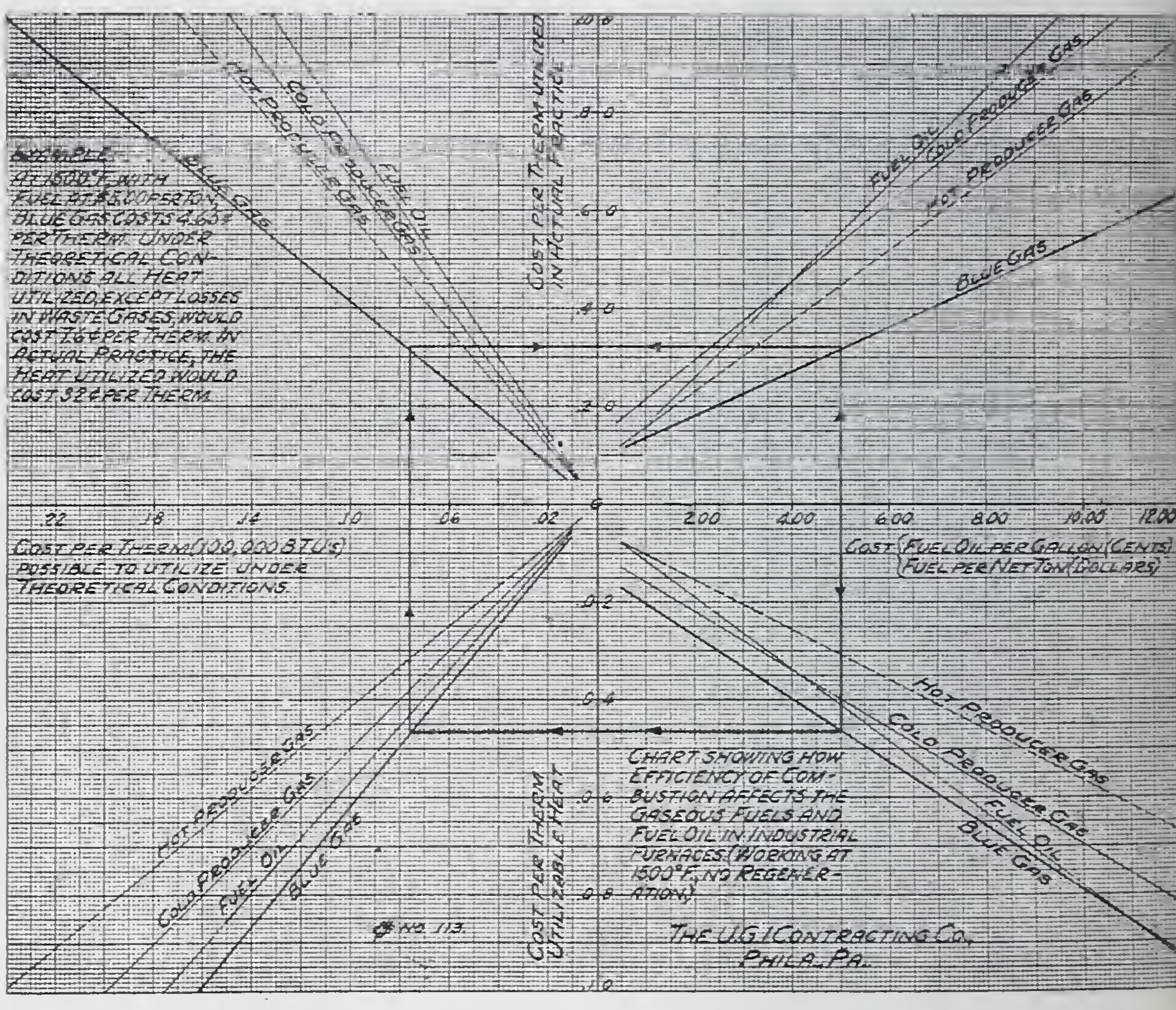

Fig. 10. Curves Showing Comparative Costs of Working with Four Fuels.

Fig. 10 shows a series of curves which have been plotted with reference to values taken from those in Fig. 9. They have been developed to show by inspection the comparative cost of heating

with four of the fuels mentioned; given the price of coal, coke, or oil, as the case may be. From a consideration of fuel prices, the temperature requirements of his heating units, or the majority of them; and such factors as uniformity of conditions and of product, a fuel engineer may determine very closely the most advantageous of the four fuels for use in his plant.

The present uncertain supply of natural gas in regions where it has been plentiful until now, together with the certainty that its price will increase; the enforced extra cost of makeshift auxiliary oil firing equipment, and the oil fuel; and the very evident contrast in the use of the two fuels; are factors which cause an ever increasing demand for artificial gas.

ACKNOWLEDGMENTS

The writer is greatly indebted to the officials of the U. G. I. Contracting Company, of Philadelphia, and especially to Messrs. D. J. Collins, J. H. Taussig and Charles J. O'Donnell, for the encouragement and courtesy shown in the matter of supplying many of the facts, and all of the illustrations and tables, presented herewith, together with data acknowledged in the footnotes. Mr. E. J. Stephany and Mr. Robert Young of the Philadelphia Company, Pittsburgh, have supplied facts concerning the making of artificial gas in the Pittsburgh district.

Among the printed sources of information consulted, some of which are referred to in the foregoing, are the following:

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DISCUSSION

Mr. A. McArthur:* It may interest the members to know that the idea of the combination of a coke-oven plant and a blue-gas plant is not new. In the Middle West recently a prominent consulting engineer of Chicago and the vice-president of a coke plant independently suggested this solution of our artificial gas problem.

A Koppers coke-oven plant in Joliet, Ill., has been heated with blue gas for a number of years, but a careful calculation has shown this method to be less efficient than ovens heated with producer gas.

A producer gas plant will give a thermal efficiency of 75 per cent. against a probable 60 per cent. in a blue-gas plant. The operating costs per million B.t.u. are less in a producer plant, which would make the latter the ideal generator for industrial gas.

Mr. A. E. Blake: I am glad Mr. McArthur has cited a case which corroborates my own opinion on the matter of the industrial future for mixed gas. Suitable acknowledgment as regards the former practice with mixed gases will be found in the paper.

The operating costs for a producer plant which *really produces clean, cold gas* will be found quite different from those for a raw-gas plant. Fig. 10 and 11 are intended to aid the reader to make the most advantageous selection. Raw producer gas costs less to-day than natural gas, yet not every manufacturer is rushing to install producers. The question of high temperatures in small and medium sized furnaces cannot be disregarded.

Mr. J. H. Taussig:† About a year ago, I had the privilege of entering into a discussion of a paper by Prof. Fred. Crabtree which touched upon water-gas in some detail.

Blue water-gas for industrial uses is not new practice in England and Germany, but it may be considered somewhat new

*Sales Engineer, The Koppers Co., Pittsburgh.

†Gas Engineer of Sales Department, U. G. I Contracting Co., Philadelphia.

in this country. In Europe, where natural gas is lacking and oil is more costly, blue gas has been one of the most important fuels of industrial plants.

In the past, there has been no incentive to go into the manufacture of blue-gas apparatus in this country, though we have been manufacturers of carbureted water-gas apparatus since the year 1882. Oil and natural gas have been so cheap and plentiful in this region that water-gas seems to have been forgotten. Since the war began, everything has been upset, including prices of fuels —particularly oil and natural gas—and it looks as though they would not be lowered. We soon realized that water-gas would make a spendid substitute.

There are certain features of Mr. Blake's paper that I think should be emphasized. On paper, blue gas is an expensive fuel. Coke costs more than coal, and a blue-gas generator is not quite as efficient, thermally, as a producer. We can get efficiencies between 64 and 70 per cent. with blue-gas apparatus, using a waste-heat boiler; while a producer gas plant might give from 70 to 75 per cent. efficiency in making cold gas. It should be made clear, however, that while theoretically, at say a furnace temperature of 1500 degrees F., water-gas shows a combustion efficiency only 25 per cent. greater than cold producer gas does, in actual practice, in industrial furnaces, blue gas usually gives double the efficiency of cold producer gas. That is a very important feature to be considered.

Where the heating must be non-regenerative, and the gas must be clean for extensive distribution, blue gas is especially good. Producer gas distribution over a large plant requires a tremendous piping system. It has a specific gravity of about 1.00 while blue gas has a specific gravity of only 0.55; the mixed gas is still lighter. At the same line pressure, for a given size of pipe, about four times the number of heat units can be transmitted with water-gas as with producer gas. That is quite an item in a large plant. Blue gas can be used to gain the highest temperature required in gas furnaces, without recuperation or regeneration, whereas cold producer gas requires this treatment at temperatures above 1700 or 1800 degrees F. Blue gas can also be used on regenerative furnaces, where the work and shop conditions are

of such a nature as to permit it. In heat-treating work, blue-gas furnaces are very much more easily regulated and do not permit scale formation on iron and steel as readily as those fired by raw producer gas.

A producer-gas-fired, heat-treating furnace, especially for hardening steel tools, or balls, and similar work, must operate with quite an excess of gas, while a blue-gas furnace can be regulated to operate with gas and air in theoretical proportion.

I would like to emphasize particularly the fact that in the Pittsburgh district, a combination of coke-retort plant and blue-gas plant will prove to be the *cheapest source for artificial industrial gas fuel.* To make 1,000,000 B.t.u. of mixed gas in a United Gas Improvement Company combination plant, with coal at $3.50 per net ton, would cost about 30 cents, exclusive of investment charges. The investment cost at 12 per cent. would make an additional cost of 15 cents, making the total cost about 45 cents per million B.t.u. Is this not an attractive proposition for a fuel that can be used for all purposes with at least as much efficiency as natural gas? I have heard that the price of natural gas in this district is going away up, and the sooner you look forward to some substitute, the better off you will be.

It might interest you to know that with coal at $3.50, the equal number of heat units in combination gas would be equivalent to 6.5-cent oil, while with coal at $5 per ton, the gas will compare with eight-cent oil. This includes the investment cost for gas, while the price of oil is merely that for its delivery into the storage tanks. Comparisons on the basis of production have shown the ratio between this oil and mixed gas to be $3.50 coal and three-cent oil, or $5 coal and four-cent oil.

MR. A. E. BLAKE: One advantage might be mentioned as to why oil is used as a marine fuel. I understand the space between the inner and outer shells of a steel hull is used for the storage of oil—space which can not be utilized for solid fuel.

MR. J. M. G. FULLMAN:* What is the approximate cost of a plant of minimum size for efficient production?

*Works Manager, National Metal Molding Co., Ambridge, Pa.

MR. A. E. BLAKE: That is not an easy question to answer. I can answer part of it by saying that probably the smallest commercial blue-gas set that can be purchased is known as the four-foot set. That can be used under special conditions, and it is used by municipal gas companies to use up coke in making carbureted water-gas. It would be very advantageous as an auxiliary in some plants in this district where temperature requirements are mostly low, but where there might be a few high temperature requirements. Mr. Taussig might tell you about the costs.

MR. J. H. TAUSSIG: I haven't any figures handy that will give you definite costs, but a few figures I have in mind are those in a plant of some size. The interest on investment at 12 per cent. is equivalent to 8.5 cents per million B.t.u. for a complete blue-gas plant with a waste-heat boiler. That was a plant of two or three units. To find the cost of a million B.t.u. as gas made with a combination coal-gas and water-gas plant, add to the cost of the coal one dollar as the cost to gasify it, and divide the sum by 15, the number of million B.t.u. to be had from a ton of coal. The result will be the cost of a million B.t.u. of mixed gas. Add to this figure 15 cents to cover investment charges, etc., and the overall cost is obtained. Thus with coal at $4 we have:

(\$4.00 + \$1.00) ÷ 15 = 33 1/3 cents.

33 1/3 cents + 15 cents = 48 1/3 cents.

Natural gas at 45 cents, with 1000 B.t.u. per cubic foot, costs 45 cents per million B.t.u.

MR. STRICKLAND KNEASS, JR.:* The average steel plant has grown within the last few years and the steel departments have been crowded by new equipment and by mills placed so as to reduce the handling charges on the product. The available space for storage has been decreased and the volume of traffic on the transportation system has been materially increased.

In order to conserve the sensible heat of the producer gas commonly used, it is necessary to place the producers close to the

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furnaces. As blue water-gas may be distributed for large areas without clogging the pipes and yet serve to produce the required temperatures, the installation may be placed at a point outside of the producing area of the mill. Such an installation saves for productive work the area required by the producer plant and the coal-, ash-, and dust-handling systems. The number of cars handled on an already crowded transportation system will be reduced by that required to transport the coal, ashes, and dust.

I would like to ask a question regarding the sizes of fuel which can be used in water-gas sets. From the by-product plants we obtain three grades called respectively, breeze, domestic, and furnace coke. What sizes may be charged into a water-gas plant in order to produce the gas efficiently?

Mr. J. H. Taussig: We have run on pea coke; I cannot say how efficiently, because the tests were not very accurate. We used several thousand tons of this at a coke-oven plant, the gas being used to heat the ovens. Pea coke is a little small to get capacities and high efficiencies. We can, however, get fair efficiencies and capacity from blast-furnace coke screenings, from nut to pea sizes. The principal losses on very small fuel, if a waste-heat boiler were used, would be by the loss of carbon in the ash.

With the exception, as Mr. Blake says, of large regenerative furnaces, where the equipment is placed in a position almost adjoining the furnace, I do not see any place where producer gas could compete with the combined gas. Where you have a gas with a reaction temperature of 3500 degrees F., you are going to get high efficiency in every type of industrial furnace, whether it requires a low temperature or not. In glass manufacturing it is particularly appropriate.

For a steel plant, in connection with forge work, welding, and all other types of work, it is also particularly well adapted. For open-hearth work, when a flame is desired, the by-product tar can be injected with the gas to make a flame.

Mr. A. E. Blake: It might be interesting to know that the United Gas Improvement Company has an experimental water-

gas set in Philadelphia, and is continually working upon these problems.

Mr. Grant D. Bradshaw:* I saw some of this apparatus a good many years ago, but the use of water-gas has been discontinued at that plant. I am not in touch with the modern development of it.

Mr. E. W. Whited:† The by-product coke-oven has been developed until it can be used alone or in conjunction with a producer plant. A by-product coke-oven heated with producer gas makes gas at the lowest cost, as it is considerably cheaper to heat the ovens with producer gas than with water-gas.

The Chicago By-Product Coke Company is building a coke plant at Chicago, which will have an output of 1900 tons of coke with 14,000,000 feet of surplus gas, per day, and in addition, the usual by-products of tar, light oil, and ammonium sulphate. As additional gas is urgently needed, and as a plant of this size requires a long time to erect, they are also installing some water-gas machines which can be completed much sooner than the coke-ovens. These machines will use all the coke produced by the coke plant when it is completed and will have a daily output of 25,000,000 feet of gas.

Mr. Blake has mentioned that in using producer gas to heat a by-product oven, a temperature of about 2500 degrees F. can be obtained. This is, of course, without preheating. If both the air and gas are preheated, a temperature of about 4000 degrees F. can be obtained. Coke-oven gas with preheated air will give about 4600 degrees F. As the softening point of silica brick is about 3100 degrees F. it is quite possible to heat part of a properly designed battery with producer gas and the remainder with coke-oven gas. This method of operation gives great flexibility in the output of coke-oven gas, as the number of ovens being heated with each kind can be changed very quickly and very easily.

*President, Andrews-Bradshaw Co., Pittsburgh.

†Operating Engineer, The Koppers Co., Pittsburgh.

MR. A. E. BLAKE: Have you the figures as to the relative efficiencies where producer gas is used with regeneration and water-gas is used in direct firing but with the use of waste-heat boilers?

In the paper I referred to the *reaction temperature* of cold, clean, producer gas as being from 2400 to 2900 degrees F. This is only theoretical and in practice 2100 degrees F. is about the limit in direct firing. You are referring to raw, hot, producer gas in heating coke-ovens, of course, and that is much different.

I have heard much of, and seen many attempts made to secure, high temperatures with gas, but have never had actual proof of such a temperature as 4000 degrees F. being attained.

MR. E. W. WHITED: I have never seen any coke-ovens heated with water-gas, but I understand it is being done to some extent at Joliet, Ill., at present.

MR. A. E. BLAKE: How about using coke-oven gas non-regeneratively?

MR. E. W. WHITED: When coke-oven gas is used non-regeneratively for heating the ovens, it is almost always done in connection with waste-heat boilers. This method has the advantage of reducing the first cost, but the overall operating efficiency is not as high. In fact, the additional investment required for preheating can be justified practically always by the increased economies of operation.

MR. A. E. BLAKE: With direct fire, using coke-oven gas, the temperature of exit gases is high, hence the desirability of a waste-heat boiler. The boiler efficiency on an initial temperature of say 2300 degrees F. ought to be about 70 per cent. with a good installation, and the final waste gas temperatures about 270 degrees F., using an economizer. The overall efficiency should be high, compared to that obtaining in a regenerative plant where the final temperature of waste gases is from 500 to 800 degrees F. In the latter case it would not be practicable to utilize still more waste heat with a boiler.

MR. F. M. VAN DEVENTER:* In cities located so unfortunately that natural gas is not available, water-gas, coal-gas, or the duplex process in which the two are mixed, are the usual alternatives. The water-gas apparatus is comparatively simple, requires a minimum of space, and can be readily started up and shut down where intermittent operation is necessary or desirable.

In central Illinois cities, for example, which are located about equidistant from the supply of gas, coal, and oil, the duplex process is generally used. Kentucky gas coal, sometimes mixed with a comparatively small quantity of Illinois bituminous, is gasified in recuperative retort coal-gas benches, from which the ammonia and tar are recovered and all or part of the coke (aside from that required to heat the retorts) is gasified in water-gas generators, the balance being sold as domestic coke. The resulting mixture constitutes a very satisfactory domestic gas of about 600 B.t.u. heating value. As retort benches cannot be intermittently operated, it is customary to run them continuously at their capacity, and to operate the water-gas generator from 2 to 12 hours per day to make up the balance of the demand and keep the holders up to the proper level. With this arrangement, most of the coke is gasified, leaving only a minor portion to be disposed of.

In some cities, located near the coal fields and where transportation charges make the oil cost prohibitive, retort gas alone is made, but the duplex process seems to be the most favored.

As pointed out by Mr. Blake, most specifications for domestic gas prescribe that the flame shall be luminous. This fact, and the usual requirement of 600 B.t.u. heating value, necessitate carburetion. Since luminosity is no longer an essential property, there has been some consideration of abandoning the practice of carburetion, but while blue-gas mixture could be produced at a cost about 25 per cent. less than the present mixture, the heating value of such gas would be about 30 per cent. lower, so that if the price were rectified on the B.t.u. basis, there would be less profit for the utilities companies. These facts refer to pre-war prices, and may not be exact for present conditions. However, there is another advantage in carbureting, since the smaller volume per unit quantity of heat effects a saving in the initial cost

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of the pipe system and in the operating cost, which become very large items in a system serving a large city.

Mr. A. E. Blake: The increased cost of oil is such as to make all previous prices void, as Mr. Taussig has brought out in his discussion.

It is true that there is some difference in the distribution of gas of low heat content as compared with that for gas of higher unit heat value, but this would be appreciable only when considering distribution on a very large scale, as in the case of a city. This matter is referred to in Mr. Taussig's article in the *Gas Age* (vol. 45, May 10, 1920, p. 381), where the relative pipe diameters for several gases are stated. In this district, nothing should prevent the utilization of existing natural gas piping in factories, with the artificial gas at say ten pounds pressure which would enable the use of the jet entraining system already referred to and make air ducts unnecessary.

Mr. A. C. Fieldner:* While it has long been recognized that coke is a more desirable fuel than bituminous coal in water-gas apparatus of present design, considerable headway has been made in the use of this fuel as a substitute for coke. This is particularly true in the Central States where the supply of high-grade coke has been very limited and uncertain during the past few years, and where coking coals of low sulphur content were available in quantities. In fact, with the present difference in price of coal and coke, it is possible to realize a marked saving when using a coking bituminous coal as a generator fuel.

Difficulties have been encountered in the use of such fuel, but they have, to a large extent, been overcome. One of the chief obstacles in the way of the more general utilization of this fuel for water-gas manufacture, is the fact that, *with normal operation,* the capacity per unit of time is reduced. This, of course, is a serious problem for plants operating at capacity with coke fuel; however, this difficulty can, to a large extent, be remedied by a changed method of operating, and can be entirely remedied by a combination of the latter with a change in the design (or propor-

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tions) of a water-gas set. I am here referring more particularly to a carbureted water-gas set.

It is to be noted that Mr. Blake states that "for continuous twenty-four hour service, the best practice at the present time calls for the utilization of the sensible heat of the gases coming from the generator, and of the heat of combustion of all carbon monoxid generated during the air blow." This is doubly true when making carbureted water-gas from bituminous coking coal. The reasons why this is so are apparent when consideration is given to the following.

The average value of the blue gas from coke fuel is 300 B.t.u. per cubic foot, while that from the coal is 335 B.t.u. Also the volume and quality of the blast gas is appreciably greater when the latter fuel is used. In other words, when making carbureted gas from bituminous coal, the quality of the blue gas is so much richer than the same gas from coke, that less oil is required to carburet it to a given standard. Therefore less heat is required for heating the checker chambers. This condition is aggravated by the fact that more and richer blast gas is available, and must be wasted at the stack in large quantities when making gas to a standard lower than 565 B.t.u. The lower this standard the greater the quantity of blast gas wasted. With the present tendency toward lower standards for city gas, therefore, the benefits to be realized by the utilization of a waste-heat boiler are at once apparent.

The general practice, in the past, in the use of waste-heat boilers, has been to utilize only the sensible heat of the gas, no consideration being given to the heat of combustion of the excess combustible blast gas. This is perhaps due to the fact that when making carbureted gas to a 600 B.t.u. standard, or better, using coke fuel, there is but little combustible gas wasted, since more oil is used per thousand, and the percentage of blue gas in the finished gas is lower. The changes brought about by the use of bituminous coal as generator fuel, and by the lower gas standard, materially alter this condition and make it particularly desirable to supply a combustion chamber in conjunction with a waste-heat boiler, for utilizing the heat of combustion of the wasted blast gas.

It is my purpose, in drawing attention to the use of bituminous coal as generator fuel, not to show that it is better fuel than coke but to point out that:

1. Carbureted gas can be made from it more cheaply than with coke, due to the fact that although slightly more generator fuel is used per thousand cubic feet, the difference in the prices of coal and coke is great enough to offset this difference. The oil per thousand is less, due to the higher heating value of the blue gas from coal fuel.

2. A still greater economy can be realized from the use of such fuel, (bituminous coking coal) when a properly designed waste-heat boiler with a suitable combustion chamber is provided. A report of the results of a study of this problem has just been completed and will probably appear in the near future as a publication of the United States Bureau of Mines. Another paper that may be of interest to those concerned in the manufacture of carbureted water-gas, is a report of experiments made, during July and August, 1920, in the use of mixed fuels, coal, and coke, on a commercial scale (making over 1,000,000 cubic feet of gas a day). This paper will probably appear in the near future as a publication of the United States Bureau of Mines.

Mr. A. E. Blake: The use of bituminous coal in place of coke is very attractive in that it enables the total gasification of coal to a first quality, or nearly all combustible gas, in one stage. It will be very interesting to have the data upon the yields of tar and ammonia. Only the bituminous coals with a sufficiently refractory ash can be used, however, due to the fusion of some low melting ashes to the grate bars of the generator. The problem, for some coals at least, might be solved by treating with predetermined small quantities of mineral matter which would give sufficient refractoriness to the ash. Dr. Fieldner has also assured me that the United States Bureau of Mines has investigated the matter of supplying gases with an odor in case they may be dangerous, and he is prepared to make recommendations for such purposes.

MR. P. A. YOUNG:* Is there any place in the United States where they use Mond gas, this being the principal product, and consider the tar as the by-product; that is, where they burn the gas under the boilers?

MR. A. E. BLAKE: I do know of a case in this district, at Irwin, Pa., where they propose to use mine waste, running as high as 50 per cent. ash, in generating Mond gas, from which they could recover tar and ammonia, using the Mond gas under the boilers. There was a great deal of difficulty about it and I understand they had to use largely run-of-mine coal to operate the plant. Your gas will contain from 12 to 15 per cent. CO_2 and that is a very unhealthy constituent to be in any gas which is to be used as fuel. Mond gas may have about 150 B.t.u. per cubic foot; but you would naturally have the dampening effect of the CO_2. The percentage of nitrogen is also high. I do not think that Mond gas could ever be a very great favorite in an ordinary industrial plant in this region, because, while there is a large yield of by-products, that is not so interesting to those who want good gas. They are making steel or glass, and the fewer of those side lines they have to handle the better they are suited.

MR. J. C. HOBBS:† I would like to ask Mr. Blake to give us an illustration of some installation which could be made in the Pittsburgh district where the use of water-gas could successfully meet the competition of any other kind of fuel.

MR. A. E. BLAKE: You mean some existing plant? I do not think of any industry in which you could not use the combined gas with suitable modification of your furnaces. I do not think water-gas or even combined gas would be the thing to use in large regenerative plants because the cost would be higher than producer gas and producer gas is generally just as suitable; but I know of a plant where they pride themselves on the low sulphur content of the steel, and in such case it is possible to re-

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†Assistant Superintendent of Power Stations, Duquesne Light Co., Pittsburgh.

move the sulphur from this mixed gas much more easily than it CO_2, can be eliminated by absorption in a basic solution in the can be removed from producer gas. In fact, you can not get it out of producer gas. That would be only a very special case. You can remove the sulphur from tar-free gas very thoroughly if desired. It is necessary to do so in the case of glass annealing. With producer gas the ware becomes frosted unless a muffle is used. But the small sulphur content of water-gas, present as SO_2, can be eliminated by absorption in a basic solution in the water seal. I am certain that traces of it would not have any effect on the surface of the glass. The gain in thermal efficiency by cutting out the muffle would leave a good balance in favor of water-gas.

The remarks which Mr. Kneass has made concerning mill space and transportation systems should be borne in mind in deciding between local raw gas producers and a central gas plant.

SULPHUR IN COAL AND COKE*

By Alfred R. Powell†

SULPHUR IN COAL

Forms of Sulphur Present. It is a well known fact that sulphur is always found in coal, the percentage present varying greatly with the type or class of coal. The amount of sulphur in anthracite is always extremely small—so small in fact that its presence may be neglected for the purpose to which hard coal is put. Bituminous coal generally contains from one to two per cent. of sulphur, but this may often run as high as five per cent. This sulphur in bituminous coal is a very unwelcome impurity, when burned, since it produces a corrosive gas, causes sulphur compounds to be present in illuminating gas or fuel gas, and is the source of the sulphur in coke. The sulphur of metallurgical coke finds its way into the pig-iron and thence into the steel, causing "red-shortness"—a source of trouble all too well known to the steel man.

It is now known that sulphur exists in coal in three types of chemical compounds. The first is pyrite or marcasite, depending on the crystalline form. Both of these minerals have the formula FeS_2. The second is sulphur in organic combination, which is generally referred to under the name of "organic sulphur." Further than the fact that this sulphur is combined with the carbon of the coal, nothing is known as to the compounds in which it exists. The third type of sulphur includes the sulphates found in coal. In freshly mined coal sulphates are present in very small quantities only.

In co-operation with Prof. S. W. Parr of the University of Illinois, the writer several years ago devised methods of analysis for the different forms of sulphur in coal, which at the same time furnished proof that these three forms and no others existed. Dilute hydrochloric acid dissolved the sulphates completely. Dilute

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nitric acid oxidized and took into solution the pyrite without touching the organic sulphur. The ratio of the iron and sulphur in this solution to correspond to the formula FeS_2 in every case showed that this was a selective method for the pyrite alone. That sulphur in the residues from these extractions was in organic combination was demonstrated by digesting with concentrated nitric acid and treating with ammonia, by which means all of the ash-free organic matter of the coal went into colloidal solution while the ash remained by itself and could be filtered out. All of the remaining sulphur of the coal was found in the ash-free fraction, showing that it was associated with the carbon and not with the ash constituents.

As to the relative amounts of the different sulphur forms found in coal, all that can be said is that in some coals pyrite is present in greater quantity than organic sulphur, while in other coals the organic sulphur is in excess. As has been stated before, the sulphates are negligible in freshly mined coal.

The following table gives the analytical results on the sulphur forms for a variety of coals. It will be noted that the organic sulphur has been divided into two types—the "humus" and the "phenol soluble." The reasons for this division need not be given in this paper, but it is to be noted how closely the sum of the separate analyses checks the total sulphur as determined by analysis.

TABLE I. SUMMARY OF ANALYSES FOR SULPHUR FORMS IN COAL

Number	23066	18847	20507	21308	21100	27224
Pyritic sulphur	0.47	0.79	0.08	0.13	1.75	1.99
Sulphate sulphur	0.07	0.23	0.01	0.04	0.71	0.32
Organic sulphur (humus)	0.50	0.46	0.44	0.42	1.01	0.39
Organic sulphur (phenol soluble)	0.12	0.20	0.02	0.09	0.77	0.32
Total	1.16	1.68	0.55	0.68	4.24	3.02
Total by direct analysis	1.21	1.72	0.56	0.71	4.25	3.06
Difference between totals	0.05	0.04	0.01	0.03	0.01	0.04

None of these samples of coal was freshly mined, so the sulphate content is comparatively high.

The physical occurrence of pyrite in coal has important practical significence as will be seen later. Dr. Thiessen of the United States Bureau of Mines has made quite a detailed study of this.

He has found that pyrite occurs in coal as coarse particles in the form of balls, lenses, nodules, continuous layers, thin sheets, or flakes, both in horizontal planes and vertical cleavage fissures; but a considerable amount of the pyrite also occurs in coal in the form of microscopic particles or nodules.

Several mines in Illinois and Kentucky have been studied with respect to the distribution of the sulphur forms over the working face. It has been found that in a vertical section the organic sulphur is practically non-variant in quantity in coals from different levels of the seam. It is known that the total sulphur in coal from different parts of the same mine varies between wide limits; these results, therefore, show that the variation in sulphur content is due to an unequal distribution of the pyrite, the organic sulphur being almost constant for the same mine.

While the coal is underground, unexposed to the air, the changes taking place in the coal sulphur proceed at a very slow rate—as slow, in fact, as the evolution of the coal itself. Coal along the working faces of the mine, or in storage, exhibits quite a different behavior, however.

When pyrite is exposed to air at ordinary temperatures, a slow oxidation takes place with the formation of ferric sulphate and sulphuric acid. The presence of these two compounds in mine waters is undoubtedly explained by such a reaction. The writer has observed a large deposit of ferric sulphate crystals deposited in the form of a stalactite under a coal storage bin. Other instances have been reported of the presence of ferric sulphate around coal which has been in storage for several months.

In the laboratory, the same phenomenon has been observed. Analyses for the sulphur forms in the same sample of coal made several years apart have shown a decrease in pyrite, a big increase in the sulphates, and an increase in organic sulphur. The quantitative relationships seem to indicate that pyrite oxidized to ferric sulphate and sulphuric acid, and that the sulphuric acid then reacted, partly with ash constituents to form sulphates and partly with unsaturated organic substances in the coal, which explains the increase in organic sulphur.

Removal of Sulphur from Coal. High-sulphur coal generally has a high content of pyrite and this, in turn, is generally

associated with high ash. Both sulphur and ash are objectionable constituents in any coal, and this fact has led to the development of methods for their removal.

Coal-washing processes are based on the fact that coal and its impurities have different specific gravities. That of coal generally lies between 1.25 and 1.35. Clean shale has a specific gravity of about 2.3 and the specific gravity of pyrite lies in the neighborhood of 5.0. In order to separate these constituents efficiently the coal must be crushed and sized. The finer the coal is crushed the more distinct the separation may be made. On the other hand, fine coal is very difficult to dry and is unsuitable for many purposes.

Coal-washing apparatus may be divided roughly into two classes—jigs, and concentrating tables. Many different types of jigs exist, but the underlying principle is largely the same in all. The raw coal flows into a trough or box containing water. The bottom of the box is a sieve through which water enters in regular pulsations. This causes the raw coal flowing over the sieve to separate into two layers, the purified coal at the top and the ash and sulphur constituents at the bottom. Each layer may then be drawn off through a proper outlet.

Concentrating tables consist of a slightly sloping surface, down which the water and raw coal flow. Riffles or slight elevations run across the table at right angles to this flow. These riffles tend to hold back the heavy ash constituents and pyrite, while the lighter coal is carried on. The table is sloped slightly sideways so that the waste material is carried to the end of the riffles and there discarded. As compared to jigs, tables are capable of handling finer sized coal.

Various devices are employed for dewatering the washed coal. Among these might be mentioned settling tanks, dewatering elevators, Dorr thickeners, and centrifugals for the final drying. The modern coal washery is a complicated lay-out, and it is beyond the scope of this paper to do more than indicate the principles involved.

The coal-washing process does not, of course, remove any of the organic sulphur of the coal. In fact, with the removal of the ash constituents, the organic sulphur is concentrated in the same

proportion as the pure coal is concentrated, so that the percentage of organic sulphur in washed coal is higher than in the corresponding raw coal. As has been shown earlier in this paper, a considerable portion of the pyrite exists in the coal in the form of microscopic particles, and, like the organic sulphur, this form is not touched by the washing process. The efficiency of the washing process for sulphur removal is determined, therefore, by the proportion of the total sulphur which exists as coarse-grained particles of pyrite, as well, of course, as the inherent efficiency of the apparatus used. In general, it may be said that ordinary washery practice reduces the sulphur in coal 25 to 40 per cent.

Certain properties of the sulphur in coal, mentioned earlier in this paper, have suggested possible means for taking the sulphur out of coal. By allowing the coal to weather, pyrite is oxidized to ferric sulphate which in turn may be leached out with water. We have correspondence on such a case from a company in Ohio. This company was receiving large quantities of steam coal which contained about 2.25 per cent. sulphur. It was found that this could be reduced to 1.50 per cent. by the simple process of washing each carload, as received, with water from a hose line, although those in charge did not understand the reason for this reduction. The information seemed to indicate that the coal had been in storage some time before arrival. Ordinarily, such a method could have no commercial value, however, for two reasons. First, coal deteriorates when exposed to the atmosphere for any length of time; and, second, the cost in land required, in fire hazards, and in interest charges would be prohibitive.

The fact that dilute nitric acid dissolves pyrite might suggest this as a method for sulphur removal. There are four good reasons, however, why this would not be practicable. First, the coal must be finely divided; second, the coal substance is attacked somewhat by the nitric acid; third, expensive acid-resisting apparatus must be used; and, fourth, the nitric acid would be too expensive.

Oil flotation has been tried for the purpose of reducing the sulphur and ash in coal, but so far as the writer knows, this has not yet proved successful on a commercial scale. In fact, the only process in use at the present time for removing sulphur from coal, as such, is coal washing.

SULPHUR IN COKE

Changes in the Coal Sulphur when Coal is Carbonized. With a fairly accurate knowledge of just how the sulphur existed in the coal, it was possible to find out how this sulphur behaved when the coal was coked. Thus it was interesting and important to see, for instance, whether organic sulphur was eliminated during the coking process in larger proportion than the pyrite. Such information would be of value to the coke manufacturer since he could then differentiate between the forms of sulphur in the coal he purchased, favoring the form which left the least amount of sulphur in the finished coke.

It was not possible to follow this change of the coal sulphur in the full sized coke-oven, for two reasons. In the first place, close temperature control and the taking of samples at each stage of the carbonization would have been impossible; and, in the second place, the passage of volatile matter through the oven would have complicated the reactions. Observations have been made on coke-ovens, however, to confirm the total change occurring between the original sulphur in the coal and the sulphur in the finished coke. For a study of the changes during each stage of the carbonization, use was made of the laboratory apparatus described below. This was designed with the idea of coking such a small quantity of coal that accurate temperature control could be attained and, at the same time, the products of distillation could be removed before secondary reactions occurred between the volatile matter and the coking mass. The coking chamber consisted of a fused silica tube in which the charge of five grams of the powdered coal was distributed over four inches of the middle portion. The charge was heated by a "Nichrome" wound tube furnace, and temperature readings were taken by means of a Hoskins thermo-couple, the end of which rested against the outside of the coking tube at the point where the coal charge had been placed. The outlet end of the tube contained a cotton plug which acted as a tar filter and was surrounded by a copper water-bath of the same design as that used by the United States Steel Corporation for the same purpose. The by-product gas passed through ammoniacal cadmium chlorid to remove the hydrogen sul-

phid, and then through absolute alcoholic potash to detect any carbon disulphid that might be formed.

Each sample of coal was run at various temperatures, so as to determine just what had happened at each stage of the carbonization. These temperatures were generally 300, 400, 500, 600 and 1000 degrees C., and the temperature was held at the proper point just about the length of time that coal in a coke-oven would stay at that temperature. Analyses were then made for the amount and state of combination of the sulphur in all the products.

Since pyrite is known to be one of the most important sulphur constituents of coal, it was considered necessary to study the behavior of this compound at different temperatures before going ahead with the study of the coal itself. Very little of the pyrite decomposed up to 500 degrees, but at 1000 degrees C. the decomposition was complete. The following table shows the changes in the forms of sulphur in mineralogical pyrite between 0 and 1000 degrees:

TABLE II. ANALYSIS OF PYRITE BEFORE AND AFTER DECOMPOSITION AT 1000 DEGREES

Degrees C.	0	1000
Pyritic sulphur	48.52 per cent.	0.00 per cent.
Sulphate sulphur	0.16 per cent.	0.00 per cent.
Free sulphur	0.00 per cent.	21.88 per cent.
Sulphid sulphur (FeS)	0.00 per cent.	24.24 per cent.
Sulphur as H_2S	0.00 per cent.	2.56 per cent.
Total sulphur	48.68 per cent.	48.68 per cent.

These results point pretty clearly to the following reaction: $FeS_2 = FeS + S$.

It has been found that a small quantity of the free sulphur is retained in the ferrous sulphid in the form of a solid solution known as pyrrhotite or magnetic sulphid of iron. The quantity is so small, however, that the quantitative relationship is scarcely affected. In the presence of an excess of hydrogen such as that given off in the gas when coal is coked, the free sulphur is converted into hydrogen sulphid. The disposal of the pyrite of the

coal during the coking process is, therefore, very simple—half of the sulphur remains in the coke in the form of ferrous sulphid, primarily at least, while the other half goes off in the gas in the form of hydrogen sulphid.

A complete study of the sulphur distribution at different temperatures was made on a Tennessee coal, very high in sulphur. The results are given in the following table:

TABLE III. DISTRIBUTION OF SULPHUR IN TENNESSEE COAL NO. 21100

(Values given in per cent. of original air-dried coal.)

Degrees	0	300	400	500	600	1000
Pyritic sulphur	1.75	1.75	1.42	0.31	0.00	0.00
Sulphate sulphur	0.71	0.55	0.44	0.01	0.01	0.00
Organic sulphur	1.79	1.63	1.51	1.70	1.87	1.81
Sulphid sulphur	0.00	0.13	0.44	0.93	0.82	0.84
Sulphur as H_2S	0.00	0.19	0.39	1.20	1.39	1.44
Sulphur in tar	0.00	0.00	0.05	0.10	0.16	0.16
Sulphur as CS_2	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.25	4.25	4.25	4.25	4.25	4.25

It will be noted that the sulphur not otherwise accounted for is classed as organic sulphur. That this sulphur in the coal is organic has already been proven, and it seems to stay in much the same combination up to about 400 degrees. Above 400 degrees, however, a decided change takes place and it exhibits none of the original properties of the organic sulphur of the coal. Evidence points to the fact that the sulphur is still associated with the carbon of the finished coke, but the chances are that this is more of a physical combination than a chemical union. The term "organic sulphur" is, therefore, not strictly applicable after the temperature has passed 400 degrees C.

The action of pyrite when heated has already been studied, so that the disappearance of the pyritic sulphur may be accounted for by assigning one half of it to sulphid sulphur and the other half to hydrogen sulphid. This reaction begins at 300 degrees, reaches a maximum between 400 and 500 degrees and is complete at 600 degrees. In every case the hydrogen sulphid is found to be in excess of that produced by the pyrite. The most probable source of this is the organic sulphur, a portion of which is de-

composed to form hydrogen sulphid. From one fourth to one third of the organic sulphur is so decomposed. A small part of the organic sulphur also enters the tar as thiophene and other organic compounds. As stated before, the remainder of the organic sulphur, which is considerably over half of that in the coal, is changed to a very stable carbon-sulphur combination and remains in the coke. The sulphate form, if such is present in the coal, is reduced to the corresponding sulphid. In the latter stages of the carbonization and in the finished coke it will be found that the sulphid form is present in smaller amounts than that called for by the decomposition of the pyrite and the reduction of the sulphate. This is due to another reaction, more or less unexpected—namely, the transfer of a portion of the sulphur in the metallic sulphids to combination, either chemical or physical, with the carbon of the coke.

By means of these reactions the changes of the coal sulphur during carbonization have been explained. The reactions, for the sample of Tennessee coal mentioned above, are shown graphically in Fig. 1. The example given here is typical of many coals studied, all of which exhibit much the same behavior. The net result of these changes is that over half the sulphur is retained in the finished coke while less than half goes off in the volatile matter.

Certain secondary reactions, which occur in the coke-oven, but not when small quantities are coked, are of importance. For instance, it will be noted that no carbon bisulphid could be detected in the laboratory tests while this compound is known to be present in coke-oven gas. The formation of carbon bisulphid is due to a secondary reaction between the hydrogen sulphid and the red-hot coke. The hotter the zone through which the gas must travel, the larger will be the percentage of carbon bisulphid in the gas. The most important secondary reaction is that between the red-hot coke and the hydrogen of the by-product gas. By-product gas, particularly that toward the end of the distillation, contains a large percentage of hydrogen, often running higher than 50 per cent. by volume. The effect of hydrogen, when passed through red-hot coke, may be observed in the following results on a coking coal from the Joliet plant of the Illinois Steel Company:

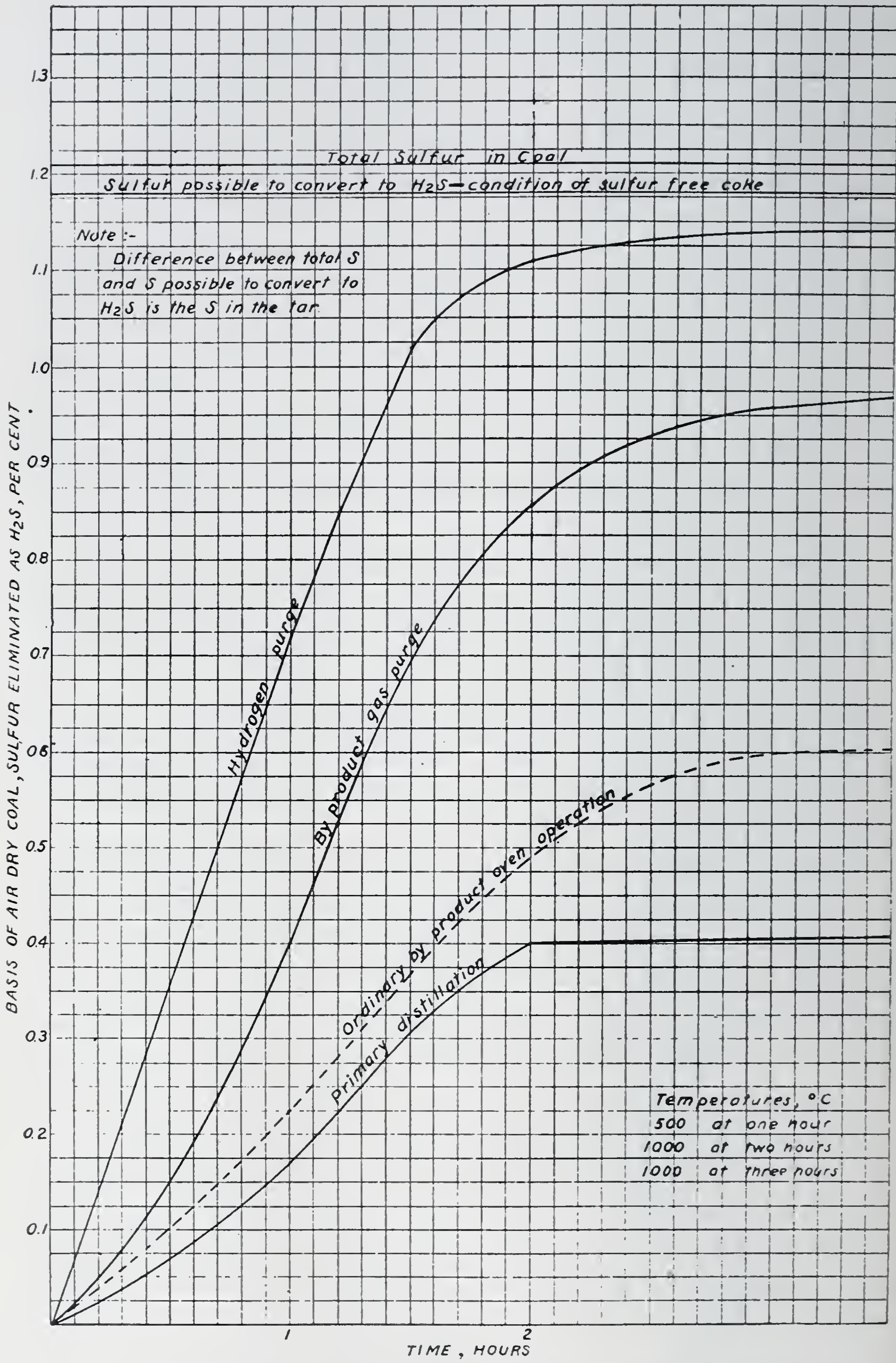

Fig. 1. Curves Showing Variations of Sulphur Constituents at Successive Temperatures of Distillation of Tennessee Coal No. 21100.

TABLE IV. DESULPHURIZATION BY HYDROGEN IN COKING TEST OF JOLIET COAL

	Without hydrogen	With hydrogen
Total sulphur in coal. Per cent. air dry coal..............	0.82	0.82
Sulphur as hydrogen sulphid. Per cent. air dry coal	0.25	0.59
Total sulphur in coke. Per cent. air dry coal............	0.55	0.21
Total sulphur in coke. Per cent air dry coke............	0.75	0.29

The effect of passing hydrogen through in excess while the coke was at 1000 degrees C. is clearly apparent. A considerable part of the sulphur of the coke has been converted to hydrogen sulphid and carried out of the coking chamber as such. The coke made from this coal in a by-product coke-oven contains only 0.64 per cent. sulphur, while the coke made in the laboratory has 0.75 per cent. This difference is probably due to the diffusion of the coke-oven gas through the oven and the consequent elimination of more sulphur than would result from the primary reactions

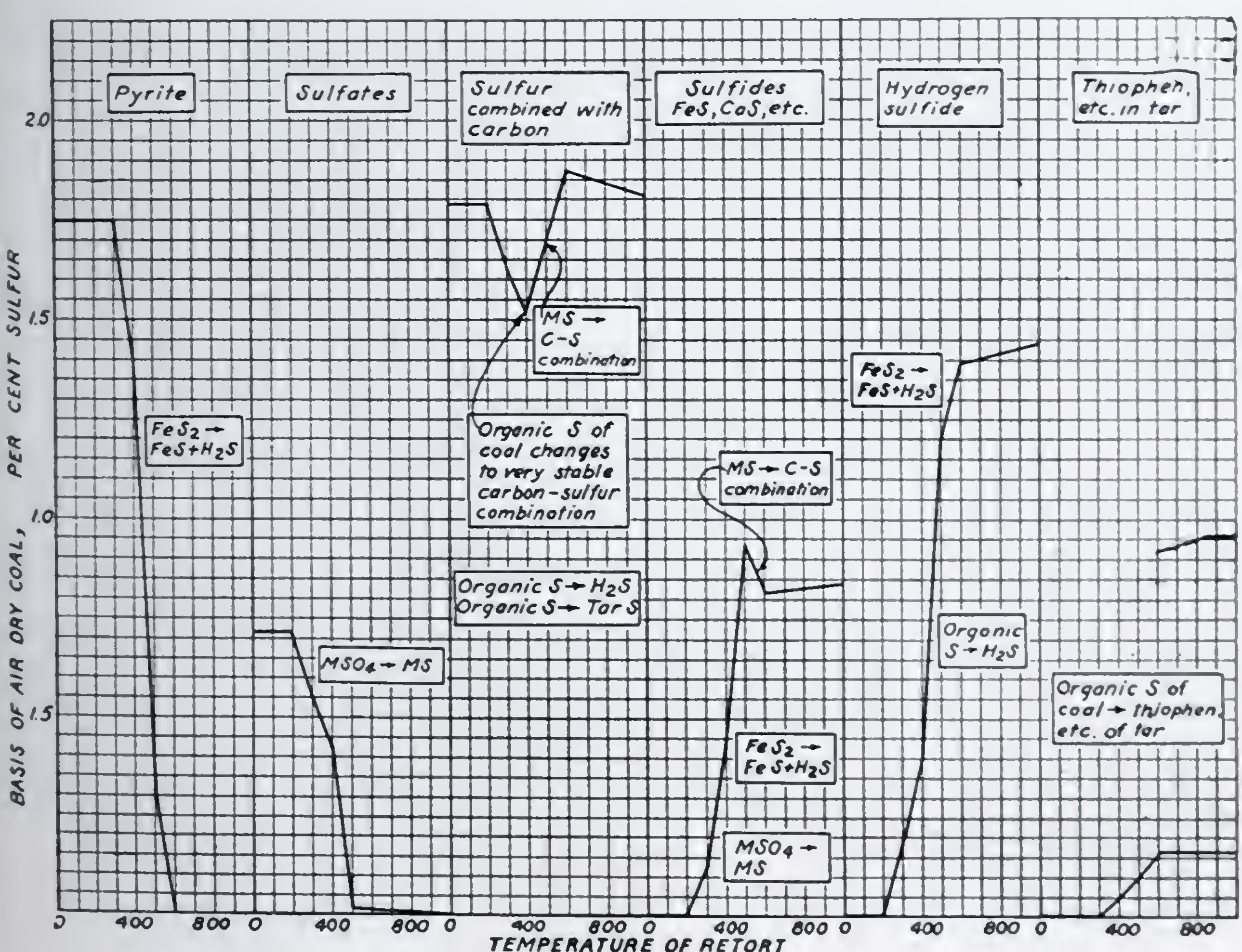

Fig. 2. Curves Showing Elimination of Sulphur as Hydrogen Sulphid from Upper Freeport Coal No. 23066 when Coked under Different Conditions.

alone. The comparative effect of pure hydrogen and a coke-oven gas containing 50 per cent. hydrogen, when allowed to act for a long time on coke from an Upper Freeport coal is shown graphically in Fig. 2. Coke-oven gas therefore has the same effect as hydrogen, but to a lesser extent.

Observations of a number of coke-oven tests have led to the conclusion that the sulphur of the coal divides quite uniformly between the coke and the volatile matter. Even with washed coals where the proportion of organic sulphur is high this ratio seems to hold good. This would seem to indicate that the forms of sulphur in the coal do not determine how much sulphur would be left in the coke. The following table bears out this point:

TABLE V. RELATION OF THE SULPHUR FORMS OF THE COAL TO SULPHUR IN THE COKE

(Data based on sulphate-free coal, containing only organic and pyritic sulphur forms.)

Coal	Organic sulphur per cent. of total S	Inorganic sulphur per cent. of total S	Sulphur in coal per cent.	Sulphur in coke per cent.	Sulphur in coke per cent. By-product oven
Pocahontas	85.5	14.5	0.55	0.45	
Washed Vandalia	78.2	21.8	1.15	1.14	
Joliet coking	68.3	31.7	0.82	0.75	0.64
Upper Freeport	58.8	41.2	1.14	1.09	
Tennessee	50.6	49.4	3.54	3.22	
Raw Vandalia	48.1	51.9	1.35	1.30	
Pittsburgh	47.0	53.0	1.49	1.51	

This table has been arranged in order, the coals with the highest percentage of organic sulphur coming first. A study of this table reveals no connection between the forms of sulphur in the coal and the proportion retained in the coke. Some observers have advanced the theory that organic sulphur would be eliminated in the coking process, but this is certainly not true. Comparing the washed Vandalia (a high organic sulphur coal) with the raw Vandalia (a high pyritic coal) the sulphur has been reduced about the same in both during the coking process.

To sum up the action of the sulphur of coal when the coal is coked, it may be stated that pyrite gives half of its sulphur to the gas and the other half remains in the coke. Likewise, the

organic sulphur divides almost half and half. The sulphur of the finished coke is mostly an unknown carbon-sulphur combination, with a smaller quantity of metallic sulphid.

Objections to the Presence of Sulphur in Metallurgical Coke. Pig-iron always contains a certain amount of sulphur, the source of which lies almost entirely in the metallurgical coke used in the blast-furnace. The presence of this impurity in the iron is most objectionable, since it is almost impossible to remove it in later operations. In the finished steel the sulphur will exist in the form of ferrous sulphid, which, at the rolling temperature, forms globules having little cohesion, thereby causing the steel to split and crumble. This is corrected to a certain extent by the addition of manganese to the steel, but under any conditions the sulphur content of the steel is a big factor in determining its value.

The sulphur content of the pig-iron may be regulated to a certain extent by the composition of the blast-furnace slag. The sulphur of the coke enters the iron as ferrous sulphid, but in the presence of a basic slag a great deal of the sulphur combines as calcium sulphid, which is soluble in the slag and thence is removed. Large quantities of basic slag are hard to handle, however, and decrease the capacity of the blast-furnace, so this method of decreasing the sulphur has its limitations.

The Desulphurization of Coke. The decreasing supply of low-sulphur coals for the manufacture of metallurgical coke has emphasized the need of some process for the production of low-sulphur coke from high-sulphur coal. Washing as a means of decreasing the sulphur in the original coal has already been mentioned. We shall now consider methods for the removal of sulphur from coke itself.

The sulphur of coke is very stable, and very hard to remove without destroying the coke itself; and the fact that we are dealing with material in solid chunks makes the problem of sulphur removal very difficult. Schemes have been proposed and patents taken out for processes making use of steam, air, chlorin, and carbon monoxid passed through the hot coke, and processes in which salt, sodium carbonate, and manganese dioxid have been added to the coke. All of these have proved inefficient as desulphurizing methods, or have destroyed the coke.

The fact that hydrogen will decrease the sulphur in coke without otherwise affecting it has led the United States Bureau of Mines to investigate such a process. The laboratory data on this have already been given. Tests on coke-ovens have been conducted under our observation in which the purified coke-oven gas was passed back through the oven. Very encouraging results have been obtained, but the investigation is still largely in a state of evolution.

At the present time the following conditions seem to be most essential for this desulphurization process. The temperature must be as high as possible, a large volume of hydrogen or hydrogen containing gas must circulate through the oven at a fairly fast rate, and this must then be purified, preferably by a hot process, and then recirculated.

It has been said by a blast-furnace superintendent that desulphurization of a metallurgical coke analyzing over one per cent. of sulphur, so that the sulphur would be reduced 25 per cent., would be worth one dollar per ton. From an economic standpoint the problem of sulphur reduction is, therefore, well worth considering.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation for suggestions and assistance in the work described in this paper to Mr. A. C. Fieldner, Supervising Chemist, and Dr. Reinhardt Thiessen, Chemist, Pittsburgh Station, United States Bureau of Mines; Prof. S. W. Parr, University of Illinois; Mr. J. R. Campbell, Chief Chemist, H. C. Frick Coke Company; Mr. J. V. Freeman, Chief Chemist, Central Laboratory, Illinois Steel Company, and many others who have co-operated at various times.

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DISCUSSION

Mr. W. F. Elwood:* In coking coal in bee-hive ovens I have found that if the ovens are kept hot and the gases kept circulating properly, it is possible to burn off considerable more sulphur than if the ovens were kept cool and the gases lagging. The chemical investigation of the results from such action suggests to me a possible breaking down of the sulphids and, to a certain degree, the organic sulphur; also a reunion of the sulphur with the iron to form iron sulphid and with the carbon of the coke to form bisulphids. The fact that these gases are permitted to lag seems to account for certain high sulphur resultants.

Dr. Alfred R. Powell: I am not thoroughly familiar with the action of the sulphur in the bee-hive oven. Are the conditions to which you refer, oxidizing or reducing conditions?

Mr. W. F. Elwood: It is easy enough to start the proper oxidation but if, for one or more of many reasons, the gases fail to do their part—have no kick, as an automobile driver would say—the finished coke will show the effects of it. These are my present ideas resulting from research of several years and including many ovens of both the bee-hive and Belgian (rectangular) type. I have often heard of high percentages of sulphur being burned off, but I believe that 36 per cent. is a good average.

Dr. Alfred R. Powell: I wonder if something like that is occurring because the sulphur in the gas does reach a certain concentration at which sulphur from the gas is absorbed by the hot coke. If you figure how much sulphur would be retained in the coke of the by-product oven, on the basis of saturation of the gas for hydrogen sulphid, a very much higher percentage of sulphur would be present in the coke than is actually obtained. It seems that the gases that first come off, which are very high in hydrogen sulphid, get out of the way before the coke gets hot enough to absorb them; so it is largely a matter of getting those

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high-sulphur gases, that you get at the first part of the carbonization, out of the way before they come in contact with the hot coke.

Mr. W. F. Elwood: In case the sulphur is not burned off properly, say in an oven charged with 32 to 36 inches of coal, it is almost certain that you will find the high sulphur in the top and bottom butts, which results are very convincing.

Dr. Alfred R. Powell: In the bottom, you get the primary reaction alone, and in the top butt you get the reunion of sulphur in the gas with the coke. I found this confirmed in the experiments which the United States Bureau of Mines ran at the Johns Hopkins University. We found that the coke on the bottom of the retort was the highest in sulphur, the center was the lowest in sulphur, and the top contained more sulphur than the middle but less than the bottom. In the bottom we had the primary reactions alone, since none of the gases sweep through this portion to carry out any of the sulphur. In the center there was a decided desulphurization; and in the top, where it is hot, there is a reabsorption of the sulphur, just as you mention.

Mr. W. F. Elwood: May I intrude on your time a little more. Recently I have conducted research work to determine possible elimination of sulphur by quenching. If it can be established that the sulphur eliminated in this way is of sufficient importance, it is possible to control the quenching to a still further advantage. I haven't any figures that I care to make public at this time, but I feel safe in saying that this is of importance to coke producers.

Dr. Alfred R. Powell: Anybody who has been around an oven while they are quenching, notices the smell of hydrogen sulphid very decidedly. I remember a paper of Mr. J. R. Campbell before the American Institute of Mining Engineers in which he claimed that some H_2S was eliminated in this quenching, but in negligible amounts, although the odor was quite distinct. There has been some work done by using very dilute hydrochloric acid and quite an elimination of sulphur is reported.

MR. J. R. CAMPBELL:* I have known of Dr. Powell's activities along this line for quite a while and have been following them with considerable interest. We have been more or less closely associated for the past year, working together and co-operating along another line of investigation during which I have come to know and place great confidence in him and his work, although I confess that some of his conclusions on the sulphur problem completely upset my preconceived notions on the subject. In fact, some of the things he sets forth are almost revolutionary.

Dr. Powell refers to the formation of ferric sulphate and sulphuric acid by the slow oxidation of the pyrite in coal. He says, "The presence of these two compounds in mine water is undoubtedly explained by such a reaction." Having had some experience along this line, I would like to amplify this phase of the paper, quoting from a discussion I had previously prepared for the August meeting of the American Institute of Mining and Metallurgical Engineers and which, no doubt, is already printed in the publications of that Society, although I have not seen it.

The quotation is as follows:

"Bulletin No. 529 on the 'Enrichment of Sulphide Ores' by William Harvey Emmons of the United States Geological Survey on Page 48, gives the chemistry of Sulphide Enrichment, which in my judgment, explains most logically the various reactions that take place in the Sulphide Enrichment of acid mine water:

The oxidation of pyrite is considered by many to proceed as follows:

$$FeS_2 + 7\ H_2O = FeSO_4 + H_2SO_4.$$

This equation does not express intermediate steps, nor does it represent the final products. Ferrous sulphate in the presence of atmospheric oxygen will be oxidized to ferric sulphate or to ferric sulphate and ferric hydroxide.

$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + 2Fe\ (OH)_3.$$

The hydrolyzation of ferric sulphate may first give a basic ferric sulphate, but this subsequently breaks down, forming ferric hydroxide and sulphuric acid, as indicated below:

$$Fe_2(SO_4)_3 + 6H_2O = 2Fe\ (OH)_3 + 3H_2SO_4."$$

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The matter is again referred to on page 65 of this same Bulletin as follows:

> "The oxidation of ferrous sulphate to ferric salt and the hydrolyzation of ferric sulphate take place very readily in the presence of oxygen.
>
> $2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O.$
> $6FeSO_4 + 3O + 3H_2O = 2FE_2(SO_4)_3 + Fe_2(OH)_6.$
> $Fe_2(SO_4)_3 + 6H_2O = 2Fe\ (OH)_3 + 3H_2SO_4.$"

We have made careful examination of the natural precipitate, commonly called "sulphur mud," from acid mine water which usually has approximately the following composition:

	Dry	Wet
Moisture		70.50%
Silica	.70%	
Alumina	3.97%	
Lime	nil	
Magnesia	nil	
Alkalies	not done	
Iron oxid	63.43%	
Loss on ignition	31.82%	
SO_3	14.44%	

In the above analysis, I figure that the iron salts are present approximately as follows:

$$Fe_2(SO_4)_3 = 24.07\%$$
$$Fe_2(OH)_6 = 71.95\%$$

This is what I call a modified basic ferric sulphate, since the hydrolysis, or oxidation, of the ferric sulphate has not been completed according to the last reaction of the theoretical considerations. I also figure that a true basic ferric sulphate of the formula $2Fe_2(SO_4)_3 + 2Fe\ (OH)_3$, has the following composition:

$$Fe_2(SO_4)_3 = 78.9\%$$
$$Fe_2(OH)_6 = 21.1\%$$

Thus it will be seen that there is considerable variation from the theoretical considerations and I have bridged the gap by calling the precipitate from mine water a modified basic ferric sulphate, or a modified ferric hydrate, in some instances where the decomposition of the ferric sulphate has been very nearly complete.

It is also interesting to note that the natural precipitate from acid mine water shown above, in an air dried condition, is valuable for the removal of H_2S from artificial gas as evidenced by the following Künberger tests:

	Dry	Wet
Moisture		30.70%
Iron oxid	63.71%	
First fouling		25.52%
Second fouling		23.91%
Third fouling		20.06%
Fourth fouling		18.63%
Fifth fouling		16.02%

Thus it is pretty clearly proven that the ferric compounds produced by the oxidation of pyrite and marcasite and found in mine water are largely made up of ferric hydrate, else the natural precipitate from mine water, commonly called sulphur mud, would not be so valuable for the removal of sulphureted hydrogen from artificial gas. In November, 1911, I discussed a paper before this Society* in which I called attention to the valuable by-products to be found in mine water, caused by the oxidation of the pyrite but it is only lately that we have come to realize the importance and to negotiate a sale for them.

At the bottom of the same page in Dr. Powell's paper he calls attention to the difficulty of drying fine coal. In this connection, I wish to say that the older difficulties are largely overcome by the use of continuous rotary filter presses which are able to reduce the moisture to 15 and 20 per cent. in the cake that comes from them. This process of drying is suitable on the underflow from the Dorr thickener, mentioned elsewhere in his paper, which usually carries 50 per cent. moisture.

Reference is made to concentrator tables and in this connection I would like to point out that very lately I have made investigation of a certain type of dry concentrator table which shows very promising results and which, if ultimately successful, would offset the objections to handling fine coal in a wet way, and modifying the statements I have previously made in my paper on "Mechanical separation of sulfur minerals from coal" (page

*Proceedings, v. 27, pp. 395–399.

1781) and referred to by Dr. Powell in his bibliography. I have also had the opportunity, very lately, of examining a mechanical slate picker to supplant the use of picking belts on certain sizes too small to pick by hand, and this also looks promising. It would seem to me that the dry process of cleaning coal, sooner or later, is going to come into its own on account of the manifold difficulties encountered in handling and drying fine coal.

Dr. Powell gives a table showing the effect of decomposition of iron pyrite, which is not quite in line with the older ideas on the subject. Dr. Oscar Simmersbach and other older writers held to the view that pyrite, on heating, was transformed into magnetic sulphid of iron, or pyrrhotite, according to the formula $7FeS_2 +$ heat $= Fe_7S_8 + 3S_2$. For this reason a good many of us older chemists have been led to believe that it is bad practice to pass a magnet through powdered coke samples to remove the metallic iron produced by the grinding machinery, on account of the danger of removing the inherent magnetic sulphid of iron. With this idea in view the method of removing metallic iron by means of copper sulphate was perfected and adopted by the chemists of the United States Steel Corporation.

Some years ago I thought I had proved pretty conclusively, in my own mind at least, that by heating iron pyrite out of contact with air, the resultant product was a magnetic sulphid of iron. My recollection is that the whole product was magnetic and could be completely removed by the use of a magnet, but it seems that Dr. Powell concludes that only a small part is a magnetic sulphid. Again, it seems to me that I have read somewhere that in certain metallurgical operations, the ore containing iron pyrites is heated to convert it to magnetic sulphid of iron in order that the sulphur may be removed by the use of magnetic separators because it is so objectionable in the smelting process.

Dr. Powell's general conclusions in regard to the volatilization of sulphur during the coking process, regardless of the form in which it exists in the coal, are in accord with my own experience; that is, one half the sulphur is in the volatile matter and one half in the coke, thus giving in the coke an ultimate sulphur dependent upon the volatile matter in the coal. We usually figure about 20 per cent. volatilization of sulphur in the coking process

with the ordinary volatile matter in coals. However, with an extremely high volatile matter, the volatilization would not be so much.

I would also like to point out that the form in which sulphur exists in the coke, is a matter chiefly of technical interest and has but little practical value in blast-furnace practice; for sulphur, in whatever form it enters the blast-furnace, is ultimately in a form to be readily assimilated by the iron, unless carried out in the blast-furnace slag. At present, the only practical way of reducing sulphur in metallurgical fuel seems to be by washing the coal from which it is made, but we may ultimately reach a point where the sulphur in washed coal will be so high that the present blast-furnace practice will have to be modified. I refer to the necessity of carrying larger slag volumes, which means the building of larger furnaces and probably curtailment of the iron output. We know that a blast-furnace slag has a capacity of carrying as high as 2.5 per cent. sulphur and, if the slag volume is a ton of slag per ton of iron, we ought to be able to use a coke holding 2.5 per cent. sulphur. The present practice, I believe, is one half ton of slag per ton of pig-iron, which means that the coke cannot exceed 1.25 per cent. sulphur. In these brief remarks on blast-furnace practice, I assume that the coke contains practically all of the sulphur of the materials in the blast-furnace charge. Of course, we know that the limestone and ores contain small percentages of sulphur.

Dr. Alfred R. Powell: In regard to my statement that ferric sulphate and sulphuric acid are present in this water, I was aware that it is very much more complicated than that—that there are, in fact, basic ferric sulphates and other compounds which are precipitated in the sulphur mud. It is a very complicated process.

In regard to Mr. Campbell's comment on the decomposition, by heat, of pyrite to form Fe_7S_8, I have found in his other papers that he has thought that pyrite, when decomposed, forms Fe_7S_8. The data I have on this were obtained from the United States Geophysical Laboratory which carried on a very thorough research. The pyrite was heated to different temperatures in the

presence of H_2S. They found in every case that there was obtained FeS plus a small amount of free sulphur dissolved in it in the form of a solid solution, and that this sulphur was variable in amount depending on the partial pressure of the free sulphur in the H_2S atmosphere. This research showed pretty conclusively that this magnetic sulphid of iron did not have the constant formula Fe_7S_8, but was merely FeS with a varying amount of free sulphur dissolved in it. In the case of pyrite decomposed in the coking process, this dissolved sulphur is negligible in amount. The pyritic residue is magnetic, however, since I have found that the magnetic portion of coke is much higher in sulphid sulphur than the non-magnetic part.

MR. F. W. SPERR:* This work of Dr. Powell's is very interesting indeed. The studies of these primary and secondary reactions are bound to be of great importance not only to the coke-oven man and the metallurgist, but also to one who looks to the by-product coke-oven as a source of gas production. In selling gas from by-product coke-ovens for domestic purposes, we have to consider its purification. I should like to call attention especially to the possibilities offered in the study of the secondary reactions in the formation of carbon disulphid, to explain why it is that from certain coals we have a higher percentage of carbon disulphid than from others. The removal of carbon disulphid is much more difficult and expensive than the removal of hydrogen sulphid.

We shall also be very much interested in the equilibrium data between hydrogen containing varying amounts of hydrogen sulphid and coke containing varying amounts of sulphur, and we hope that the author will publish such data.

I should like to refer especially to Table V, regarding the relation of the sulphur forms in coal to the sulphur in the coke. I should like to ask whether I am correct in assuming that these figures are obtained from laboratory tests entirely, with the exception of that which is specially designated as sulphur in coke in the by-product coke-oven.

I question very much if you can apply the same reasoning to these laboratory tests that you can to the practical results in the

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by-product coke-oven. In the first place, I should like very much to see this sulphur distribution considered in its relation to the coke yield. I do not believe that sulphur elimination can be correctly understood by taking all the coals in order as if they all had the same coke yield. Pocahontas, as we all know, has about 85 per cent. coke yield, whereas Pittsburgh coal has as low as 68 per cent. coke yield.

It would be of little use to recalculate Dr. Powell's table on the basis of practical coke yields, but it might be of interest to show the sulphur elimination with relation to laboratory coke yields and endeavor to ascertain whether it corresponds with plant results.

From Dr. Powell's statements in connection with the table, one would assume that there is no great difference in the amount of sulphur eliminated, whether the coal contains a high or a low percentage of organic sulphur. The Pocahontas coal at the top of the table, with a high percentage of organic sulphur, shows a little difference from the Pittsburgh coal at the bottom of the table with a very low percentage of organic sulphur. Now it has been our experience that the sulphur retained by Pocahontas coal and other coals containing high percentages of organic sulphur, with some exceptions, is considerably larger than that retained in coke from coals with low percentages of organic sulphur. I have here some figures that were taken as an average of a great many analyses. Of course, we have not had the opportunity to determine by Dr. Powell's methods the percentage of organic sulphur in these coals under consideration. Most of the figures are taken from plant records covering a period of several years, but I have put these coals in the order in which they would reasonably be assumed to stand on the basis of their organic sulphur content, the highest first and the lowest last, the same as in Dr. Powell's table.

The mixture of 80 per cent. Pocahontas and 20 per cent. Pittsburgh shows 26.6 per cent. sulphur eliminated in the coking process. Going to the other end of the table and taking a Pittsburgh coal which should have a much lower percentage of organic sulphur than the Pocahontas, we find 42.6 per cent. sulphur eliminated. This large difference corresponds with a great many

other observations that we have made. The other two coals occupying an intermediate position in the table would be expected to be intermediate with respect to organic sulphur, and the amount of sulphur eliminated is about midway between Pocahontas and Pittsburgh coals.

A special investigation of the elimination of sulphur from high-oxygen coking coals, of the character of Illinois coals, would be of much interest. We should examine the effect that the oxygen of the coal may have in the removal of retention of sulphur in the coking process. In the table, I have given practical figures for two Illinois coals. Here again, I have had no opportunity to determine their organic sulphur content. It might be expected to be higher than that of Pittsburgh coal, but the percentage of sulphur eliminated is nearly the same.

I think that this phase of the subject is worthy of further investigation. I do not feel that Dr. Powell's conclusion that there is no relation between the forms of sulphur in the coal and the proportion retained in the coke should be accepted as final, as applied to practical results.

TABLE VI. SULPHUR ELIMINATION IN BY-PRODUCT COKE-OVENS

	Coke yield	Sulphur in coal	Sulphur in coke	Sulphur eliminated	Sulphur retained
Pocahontas (80%) and Pittsburgh (20%)	84.0%	0.79%	0.69%	26.6%	73.4%
Pond Creek (75%) and Pocahontas (25%)	75.0%	0.54%	0.49%	31.5%	68.5%
Alabama	75.0%	1.07%	0.94%	33.6%	66.4%
Pittsburgh	69.8%	1.22%	1.01%	42.6%	57.4%
Illinois (Saline County)	69.8%	2.48%	2.15%	39.5%	60.5%
Illinois (Franklin County)	68.4%	1.13%	0.93%	43.4%	56.6%

Dr. Alfred R. Powell: These were simply laboratory results and, of course, figures from actual practice might be somewhat different. The main thing that I wanted to bring out was that, roughly, there is not very much difference between pyrite and organic sulphur as far as sulphur retention in the coke is

concerned, and at least, that you can not say that organic sulphur is completely eliminated, as some have tried to do. In fact, your results would seem to show that organic sulphur is retained in the coke to a somewhat greater extent than pyrite.

MR. F. W. WAGNER* and MR. R. W. CAMPBELL:† In regard to the disposal of the pyrites of the coal during the coking process, it was stated that one-half of the sulphur remains in the coke in the form of ferrous sulphid, primarily at least, while the other half goes off in the gas as hydrogen sulphid. Relative to this statement we have the following data to present.

At the by-product coke plant of the Jones & Laughlin Steel Company, we have made numerous determinations to ascertain the exact distribution of the sulphur in coal during the coking process. The following results were obtained:

Sulphur in coke	60.75% of total sulphur
Sulphur as hydrogen sulphid	33.49% of total sulphur
Sulphur in other by-products	5.76% of total sulphur

A determination, made on the coal charged during this coking process, showed that 48.74 per cent. of the total sulphur in the coal was in the form of pyritic sulphur, and 51.26 per cent. in the form of organic sulphur. Assuming that the total pyritic sulphur breaks down into ferrous sulphid and free sulphur, thereby liberating one-half of its sulphur content in the form of hydrogen sulphid, 24.39 per cent. of the total sulphur as hydrogen sulphid is due to pyrites. In order to satisfy ourselves that there exists a secondary reaction during the coking process between the residual ferrous sulphid and the carbon in the coke, a series of tests was conducted in the laboratory to prove this secondary reaction.

Duplicating the temperature existing in the ovens, as nearly as possible, during a typical coking of the above coal, various known amounts of ferrous sulphid were added to coke and heated accordingly. The coke used in these tests contained no pyritic sulphur. In all cases we found an average reduction of 38.09

*Chief Chemist, By-Product Coke Plant, Jones & Laughlin Steel Co., Pittsburgh.

†Assistant Chief Chemist, By-Product Coke Plant, Jones & Laughlin Steel Co., Pittsburgh.

per cent. of the total sulphur in the coke. Similar tests were made under the same temperature conditions, with the coke itself, and in no case was a reduction of the total sulphur content noticeable. From these results it appears that a constant reduction of the sulphur content in coke is due also to a secondary reaction between ferrous sulphid and carbon.

The following table is an average of a number of tests made:

Sulphur content of original coke	0.97%
Sluphur content of original coke + FeS	1.39%
Sulphur content of coke + FeS after heating	1.23%
Average sulphur added by FeS	0.42%
Average sulphur reduced by heating	0.16%
Average reduction	38.09%

If there is a reduction of 38.09 per cent. sulphur due to the decomposition of ferrous sulphid, the remaining 24.39 per cent. sulphur as ferrous sulphid should be decomposed with the liberation of 9.29 per cent. sulphur as hydrogen sulphid. We have now shown that 24.39 per cent. of the sulphur as hydrogen sulphid is due to a primary reaction of the pyrites, and that 9.29 per cent. sulphur as hydrogen sulphid is due to a secondary reaction between ferrous sulphid and carbon, giving a total of 33.68 per cent. sulphur as hydrogen sulphid due to the pyritic content of the coal. In the table of sulphur distribution, we show that 33.49 per cent. of the total sulphur in the coal is liberated during the coking process as hydrogen sulphid. Comparing these two results, we are led to believe that the total sulphur liberated as hydrogen sulphid, in our case, is due to sulphur in the pyritic form.

MR. A. C. FIELDNER:* This discussion has been fruitful and interesting because these studies were started largely in an academic way, to determine by fundamental research the forms of sulphur in coal and what happens to them on carbonization, purely from the point of view of the scientist without very much reference to its economic application. It is a good illustration of economic results of importance that are to be obtained by this method of attack.

*Supervising Chemist, Experiment Station, United States Bureau of Mines, Pittsburgh.

For example, Dr. Powell first worked out a method for determining the various forms of sulphur in coal. With this method as a tool he was then able to find out something of what happened to these forms in the coking process. Having completed this part of the problem, the next step is to remove sulphur from the coke. This part of the problem is now being investigated. Information may possibly be obtained which will aid in removing sulphur from the gas. Dr. Powell's work opens up a fruitful field of research. The desulphurization by hydrogen looks promising. There are many difficulties yet to be solved in the commercial application of the process but some time it will become a commercial possibility.

MR. F. F. MARQUARD:* Dr. Powell's paper is certainly very interesting and may lead to some practical desulphurizing method which may go far towards solving the sulphur problem of our fuels. Up to the present time, the coke producers and the blast-furnace men have been chiefly concerned with the total sulphur content of their coke and it is altogether possible that the condition in which the sulphur exists in the coke may be a factor that would influence the absorption of the sulphur by the slag or by the iron. This, of course, is highly speculative.

The removal of sulphur from coal preliminary to coking of such coal, involves large losses of coal and expensive washing installations and it would appear to me that the solution of the problem would be to mix high-sulphur coals with low-sulphur coals in such a way as to produce a coke with uniform sulphur content, even though somewhat high, so that the blast-furnace men will be able to use it successfully in the production of high-grade iron. The very important consideration in the use of high-sulphur fuels is the uniformity of product. The by-product coke, being more uniform in size and cell structure, would lend itself more readily to the use of high-sulphur coal than the bee-hive coke, inasmuch as you have an opportunity of effecting a mixture of the various sulphur and ash coals in a manner which will insure uniformity of product.

While our coal supply is gradually decreasing, we necessarily

*Superintendent, Clairton By-Product Coke Works, Clairton, Pa.

must make up our minds to use coals of inferior quality; and to change the standard of metallurgical coke, limiting the sulphur to one per cent., cannot stand indefinitely. In many places they have used sulphur as high as 1.2 to 1.3 per cent., where sulphur content is uniform, and have produced large quantities of excellent quality iron. The sulphur problem, as I see it, resolves itself into the fact that we must accustom ourselves and our operations to the material at hand. The by-product coke works will be called upon to carbonize high-sulphur coal and the blast-furnaces must then take high-sulphur coke. This will undoubtedly require some changes in practice and possibly in furnace construction, but if the fuel is consistently comparatively high in sulphur, the furnace change can be so regulated that the slag will take care of the additional sulphur without interfering with the quality of the iron produced.

In the manufacture of open-hearth steel, sulphur specifications limit the amount of sulphur, which makes conditions very hard, at times, for the operator to meet. Some of our metallurgists claim that sulphur, within reasonable limits, is not detrimental to the physical qualities of the steel. They point out that even when sulphur is added to the ladle the steel does not take on poor rolling qualities. On the other hand, some low-sulphur heats, without ladle additions, are red-short. From this we would deduce that it is not the quantity of sulphur, but the manner in which it exists in the steel, that alters the physical properties. This takes us back to the pig-iron and the blast-furnace in which the pig-iron is produced.

For a long time open-hearth men have known that there are occasions when very high sulphur pig-iron can be charged and the resulting steel will come within specifications on the sulphur. Quite recently a theory has been promulgated that if the blast-furnace carries a high-alumina slag—that is, 18 per cent. alumina and over—the iron may contain much sulphur, yet the sulphur would be readily removed in the open-hearth process of steel making, and inasmuch as high-sulphur coke is usually associated with high-ash coke the ash would to a large extent supply the alumina in the slag and thus the sulphur introduced into the pig-iron would exist

in a form which would enable the open-hearth men to remove it in the open-hearth steel process.

In conclusion, I would say that there are comparatively small sources of fuel from which the sulphur can be removed in a practical way by washing. On the other hand, it appears to me that the final solution for the utilization of fuel containing high sulphur will be in the development of practices whereby the sulphur specification will be made more liberal and the elimination will be made through the pig-iron, slag, steel and gas, rather than from the coal.

STORES ENGINEERING

By M. T. Montgomery*

OUTLINE

INTRODUCTION

DEFINITION

Of all phases of operation which form the entity of a plant, the question of properly caring for materials has not generally received the consideration it deserves. It was not considered of sufficient importance because the development of facilities entering into the manufacturing of products demanded most of the attention of those who kept pace with the times.

Since the intrinsic value of materials has greatly increased, the investments in unapplied materials assume large proportions. The question of storekeeping has been looked upon more or less

*General Storekeeper for Receivers, Pittsburgh Railways Co., Pittsburgh.

as a function subservient to purchasing. While it is true that they are co-ordinate, the actual handling of materials should be accorded a field of its own.

The word "storing" means the placing of materials for safekeeping. This implies that the goods have a value. A great deal of money is being spent for attractiveness of premises where valuables are stored; correspondingly, much trouble is taken with the inner arrangement of such places, as well as the handling of the valuables.

A certain part of a machine is not as attractive as a piece of jewelry, or an elaborate gown, yet it costs at least as much, if not more. It is, of course, obvious that it is not necessary to display it in attractive surroundings but it ought to be taken care of just as carefully as any article representing outlay of money.

I wish to state right at the outset that while the methods of stores engineering practiced by us may not be applicable in every detail to other lines of endeavor, it is my hope however that the conclusions you draw will be helpful to you if you are confronted with the question of properly caring for materials.

The street railway business depends a great deal upon an efficient Stores Department. Since the replenishing of materials emanates from this source, we are called upon to keep up our stock of materials, in our case consisting of 8634 different items.

ECONOMIC ASPECTS

The function of the Stores Department is to give service, and this means always having enough materials in stock to fill the requirements of the operating departments. In this, 100 per cent. efficiency cannot be attained. Causes beyond human control, such as inclement weather, labor problems, and transportation difficulties, make it impossible to lay down absolute maximum and minimum quantities of materials to be carried in stock. With methods in vogue with most plants using stock cards or stock ledgers it is next to impossible to gage the proper requisitioning of materials. The importance of efficient stores engineering depends upon the adoption of a system which enables one to provide for not more than the necessary quantities.

RECIPROCAL RELATION TO PURCHASING

According to our way of doing business, we prepare and send to the purchasing agent requisitions for the replenishing of materials and supplies. We consider a requisition a potential purchase and since this means actual outlay of money too much care cannot be taken to order the proper amounts and order them in sufficient time for actual needs, taking into consideration delays incidental to manufacturing and transportation.

As I see it, the purchasing agent's function is to place orders for goods to the best advantage both as to price and delivery. It is of the utmost importance that close co-operation be observed between the two departments. We are fortunate in having a purchasing agent who fully realizes the importance of our department. We get together with him at least once a week and discuss the difficulties we may encounter in procuring materials, as he is in close touch with market conditions.

Our requisitions are prepared in such a way as to list only kindred materials on one separate requisition and if our records based on actual experience indicate that we use a great deal of certain materials during the year we give the purchasing agent the opportunity to get better prices and deliveries by ordering larger amounts on protracted deliveries.

Unless a certain repair part is peculiar to certain type equipment—in which case we of course show the maker's name—we do not show on the requisitions any preference for any vendor.

If any materials are bought to certain specifications we have these materials tested.

In these times when hardly any manufacturer's promise is being fully lived up to, the problem of hurrying materials is very important and seeing that we are in closest touch with the demand we do this ourselves.

CLASSIFICATION OF MATERIALS

All materials and supplies handled by us are classified and are known by a class number which takes the place of, and is identical with, lot numbers or catalogue numbers.

In classifying our stock we consider the physical properties of the materials and the equipment to which they belong.

Our materials are divided into five main groups:

Way and structures.
Power and transmission.
Equipment of cars.
Transportation.
General.

Each of these groups is again divided into classes according to the kind of materials used. Taking the equipment of cars, some of the classes are:

Iron, lumber, castings, bolts, motor parts, bearings, lamps, wheels, and axles.

While our classification of 76 classes may not be applicable to any other line of business, it is illustrative.

A manager of a plant, being interested in his assets represented in unapplied materials, would naturally want to know what constitutes this investment.

Fig. 1 shows an analysis of an inventory according to classes. One can see at a glance the number of months' stock on hand for each class and the explanation therof. Our class numbers which make this possible are used from the time that the material is requisitioned for until it is disbursed. The material is identified by it while in our custody.

The class number itself shows two things. The first two digits show the class proper and the rest of the digits the sequence. For instance; all bolts, nuts, and washers are in class 25. Knowing the number of sizes of machine bolts we assign certain blocks of numbers, bearing in mind possible expansion in sizes or kinds.

STORES DEPARTMENT

AIMS

The chief aim of the Department is service—first and last.

FUNCTIONS

The duties to be performed are as follows:

Caring for and handling new materials; replenishing stock;

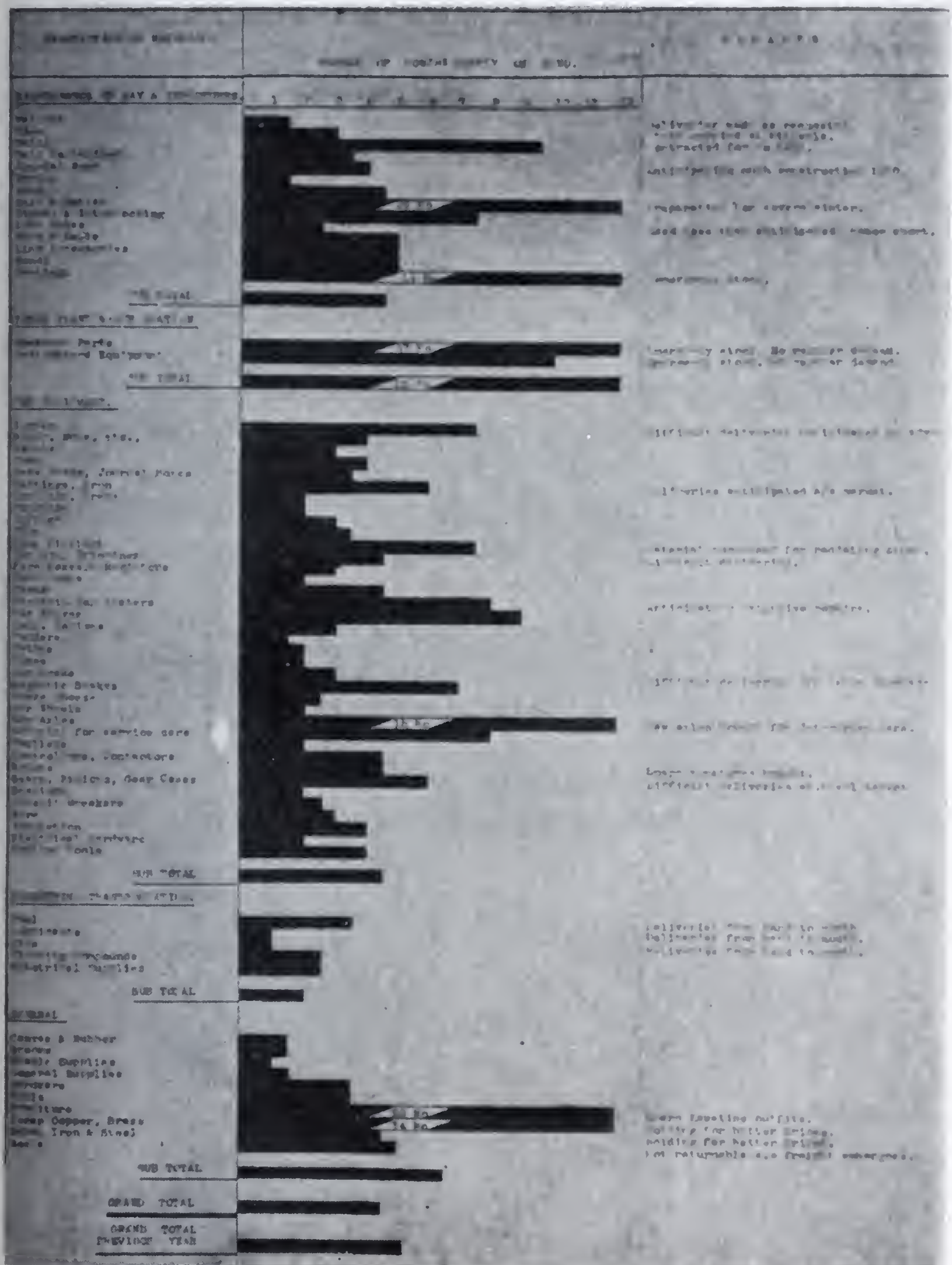

Fig. 1. Classified Statement of an Inventory Showing Supply on Hand.

delivering all supplies when and where needed; gathering up of scrap; sorting and shipping scrap; disposing of obsolete material; keeping stock records.

STORES CALENDAR

No work can be accomplished properly unless it follows a concise plan. This holds especially true in our line when so many of the things to be done depend in some measure on seasonal requirements.

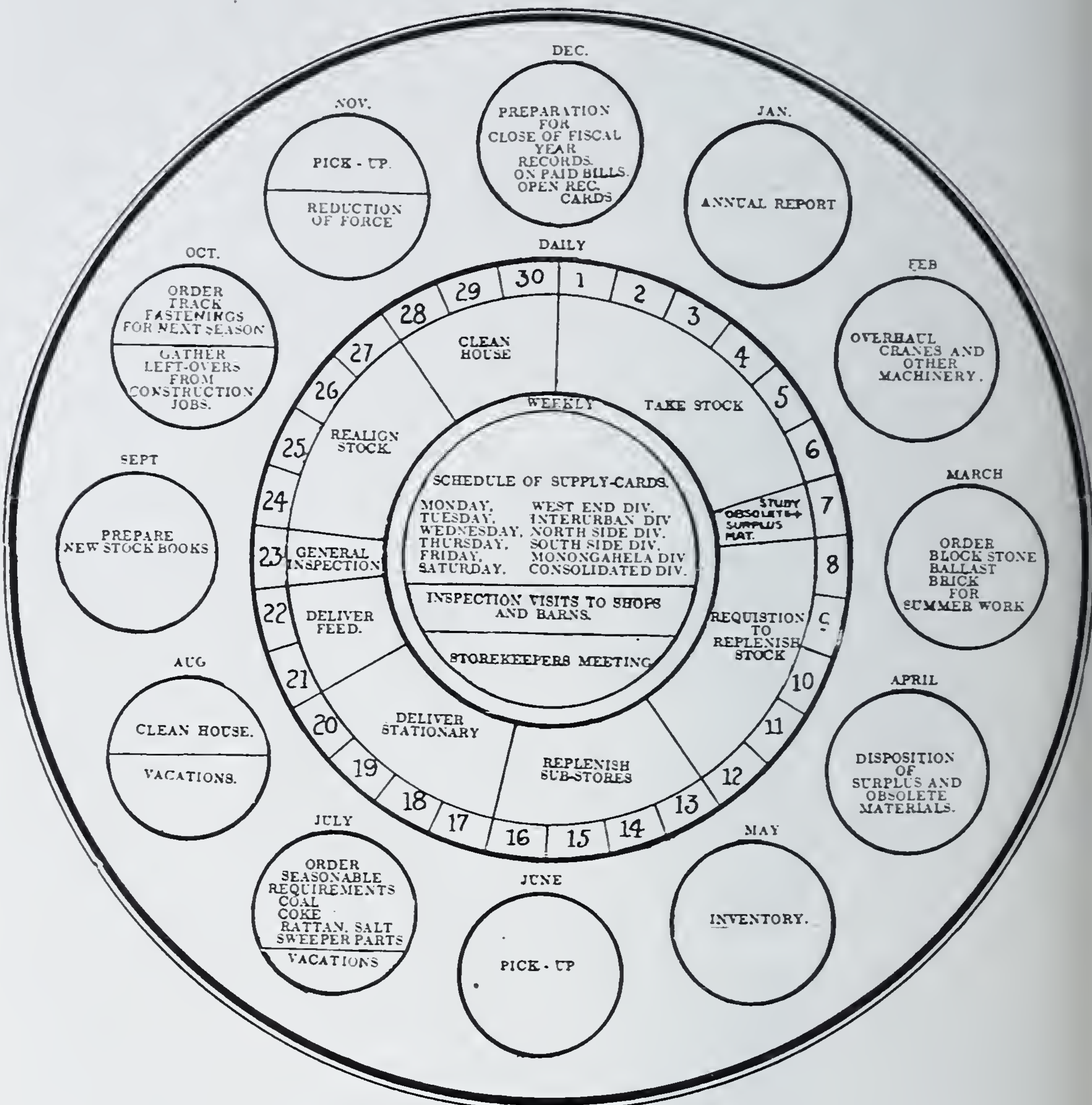

Fig. 2. Stores Department Calendar.

Fig. 2 shows the stores department calendar dividing the things to be done by months, weeks, and days. The activities noted thereon do not by any means comprise all of our functions but remind us of certain things which must be done year in and year out. Much of the street railway business can be done only at certain times of the year, and this calendar was drawn up to meet these conditions.

ORGANIZATION

No matter how clearly one may define a plan of activities it cannot be successfully carried out unless everyone in the organization does his share.

Fig. 3 shows our organization chart. While each one is assigned a certain sphere of activity it is expected he will reach out for the job ahead. We educate our employees to the best of our ability and train them for better jobs within our organization.

Owing to the nature of the business, it is necessary to conduct several branch stores in addition to the general store. These are located near the larger repair shops, and are in charge of division storekeepers.

The stores inspector is responsible for the efficient handling of the division stores and the assistant general storekeeper is responsible for the conduct of the general stores. The office work is in charge of a chief clerk and the manual operations are in charge of a foreman.

RELATION TO EFFICIENT OPERATION

Our stores calendar and organization chart are drawn up with a view to giving the most efficient service to the operating departments. Nowadays, when labor is at a premium and the question of average hourly rate of pay has greatly increased, it is imperative that the men should not loaf on the jobs for want of materials or be compelled to spend unnecessary time in making substitutes.

As a great deal of work is being done which cannot be properly classified as ordinary maintenance—such as changing over of equipment, etc.—it behooves the operating department to advise us of its expected needs, but we go further than that and through daily visits made to the various foremen, we keep in touch with their particular needs.

MANUAL OPERATIONS

LOCATION

No matter how carefully a plan may be drawn up or how efficient an organization may be on paper, stores engineering becomes a failure unless the stock is properly arranged. In our

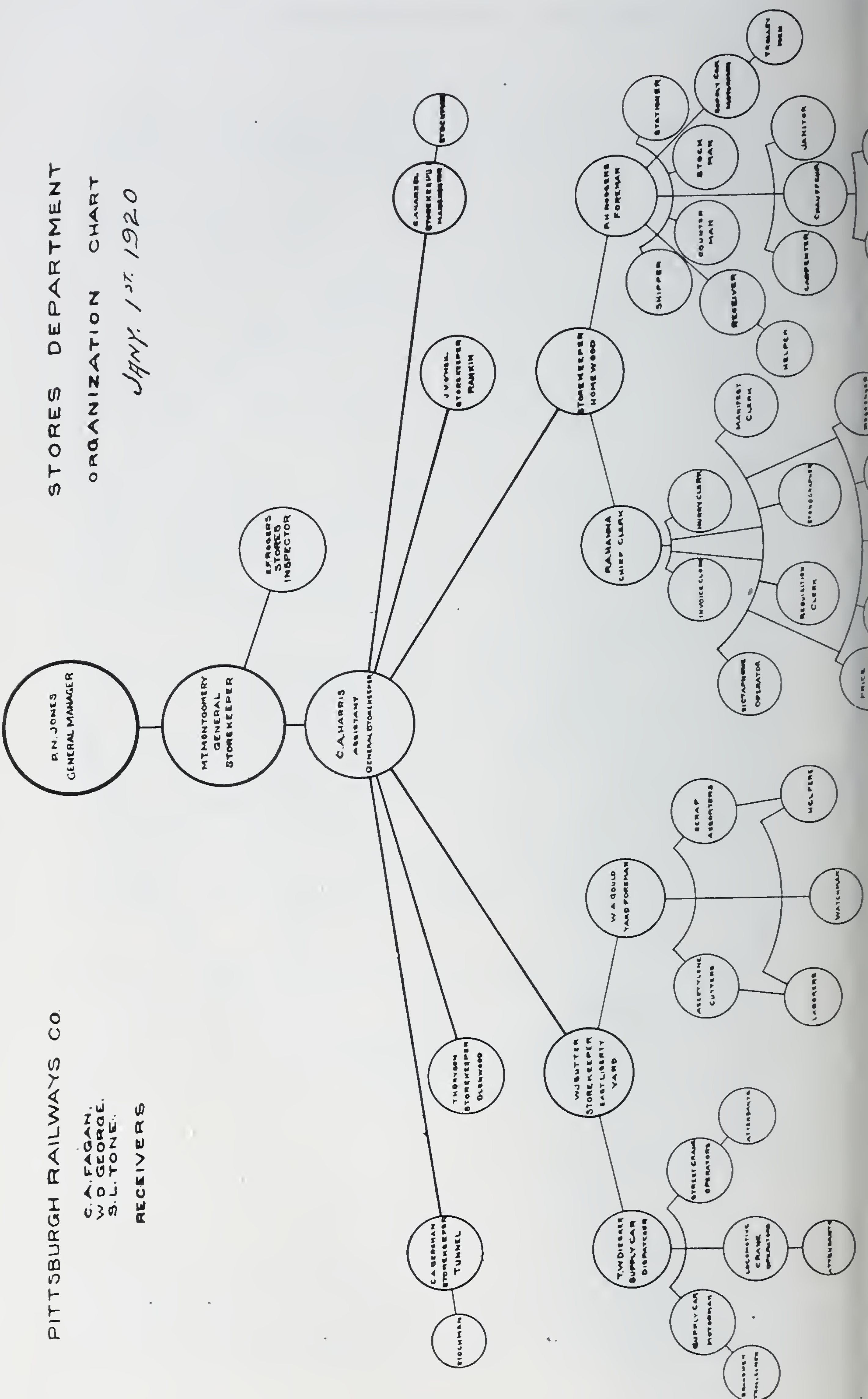

Fig. 3. Organization Chart.

business the main shops are located in Homewood, about a mile distant from the Pennsylvania Railroad Company's siding at East Liberty. This necssitates the handling of bulky materials such as rails, special work, wheels, poles, brake-shoes, ballast, sand, coal, coke, paving materials, etc., at that point to avoid unnecessary handling.

STORING

Though it may sound illogical, the first requisite of storing is not elaborate surroundings or intricate paraphernalia, but cleanliness. I have seen stores in industrial lines, as well as my own line, and many of them seem to be in need of a good bath and scrubbing. It pays to instill the sense of cleanliness into the minds of those who handle the material.

The laying out of a store is a matter that is generally given consideration long after the plant is finished. I have seen car houses and shops where everything was 100 per cent. plus as far as modern equipment, sanitation, proper labor saving devices, and all other improvements were concerned but the stores department had to content itself with inadequate quarters and makeshift arrangements. For some inexplicable reason it was thought that any old arrangement was good enough to house materials. It may be said in all justice that engineers are now giving due consideration to the proper storing of materials, as evinced by your invitation to present the experience of a storekeeper engaged in the street railway business.

Each plant has its own problems, depending on the kind of goods manufactured, therefore no set rules can be laid down regarding the proper laying out of a store; however, the principles which I am about to enumerate are applicable to any store.

Orderly piling.
Maximum visibility.
Absence of drawers.
Proper packaging.
Everything on wheels.

Our general stores are divided into sections, each kind of material grouped together forming a section. Each section is in charge of a stock man and helpers. The stock man is responsible for the physical upkeep of the section, including the storing, counting, and issuing of materials. Owing to the nature of the materials we handle we cannot adhere to standard sizes of cases, but all cases are of the same height and width. Since it is not possible, on account of the quantity of materials handled, to put the entire stock into bins we have an annex or warehouse where the overflow material is kept. Each stock man takes care of that portion of the warehause that houses material he handles.

Fig. 4 shows the lay-out of our cases. The aisle room is the same all through the stores. Waste-baskets are placed at proper intervals and they are used.

The cases are numbered. The first letter shows the section and the second letter shows the sequence of the bins. In addition, each bin is numbered and the case as well as the bin number is marked on our stock records for location reference.

A great many stores have a face board in front of the bin to allow them to use a larger size bin tag which identifies the material. We found these to be great dust collectors, therefore we did away with them and have designed a bin tag receptacle which fastens on the shelves and is so constructed that the tag may be easily removed. Bin tags written on the typewriter are placed in these receptacles. The sheet used for this purpose is perforated so that it is flexible. On this tag we give full description of the material, class number, and also cross reference to the stock record.

Materials like pencils or small tools which are apt to travel fast if not properly looked after are kept locked up, with the keys in possession of the stock clerk. See Fig. 5.

Fig. 6 shows an oil house which is a source of great pride to us. That portion of any store, as a rule, is the least presentable.

By insistence on scrubbing the floors once a week with a mixture of caustic soda and sawdust we manage to keep the floors absolutely clean.

Our iron and steel stock is kept in the same orderly way as the rest of our material. A scale, placed in the middle of the lay-out, runs on tracks and so facilities handling. See Fig. 7.

Fig. 4. Arrangement of Cases.

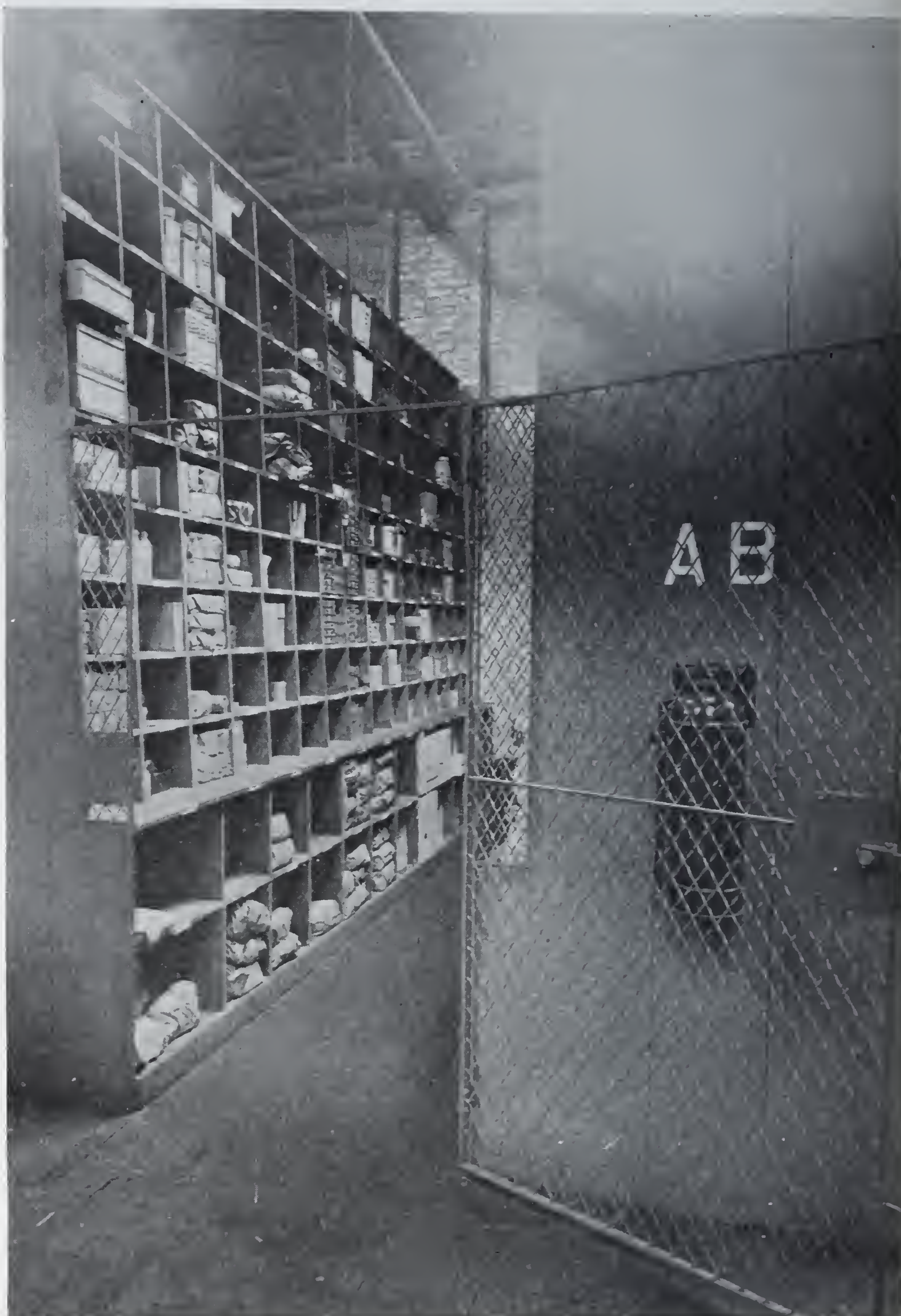

Fig. 5. Certain Materials Kept under Lock and Key.

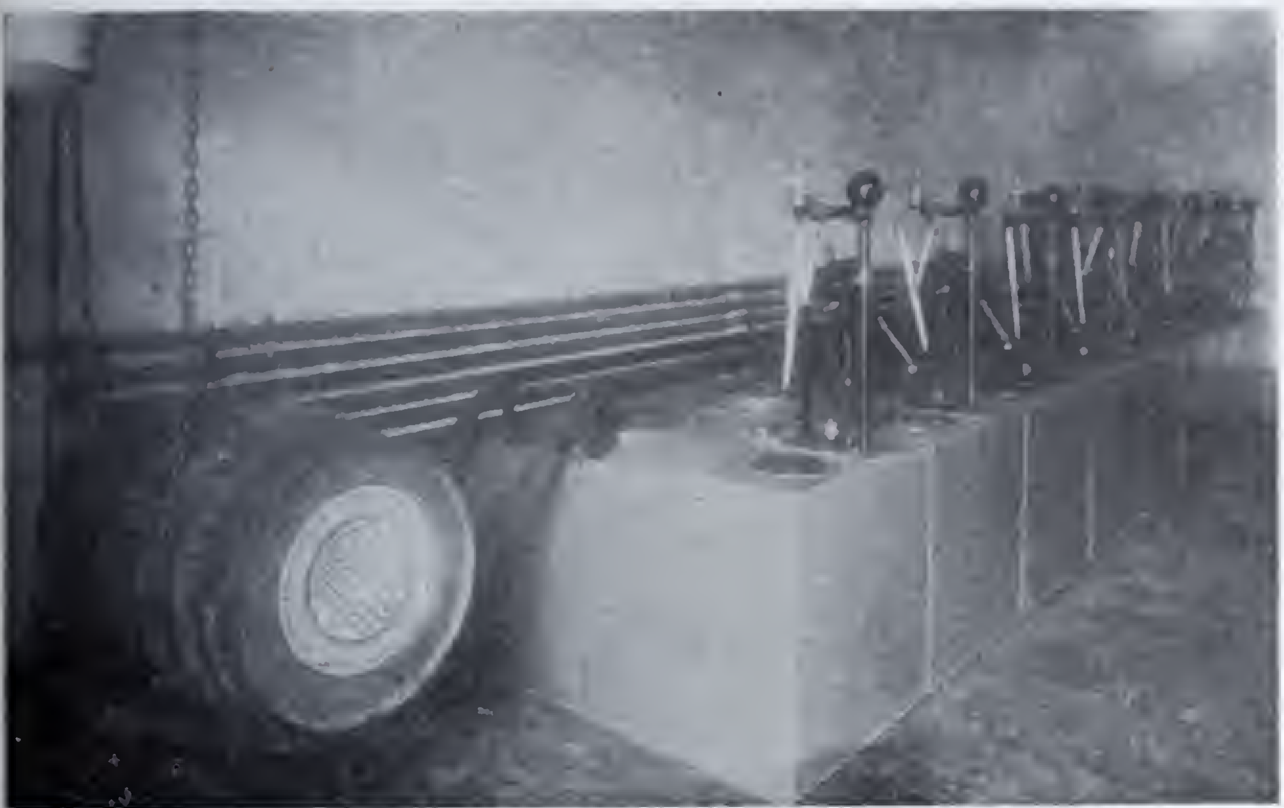

Fig. 6. Oil House.

Fig. 7. Iron Rack Scale on Wheels.

Owing to lack of space we are compelled to house in the open a great many materials of bulky nature which do not deteriorate in inclement weather.

Fig. 8. View of Yard.

Fig. 8 shows a general view of our yard.

Orderly Piling. The first requisite of stores engineering is cleanliness, and nothing can be kept clean unless piled in orderly fashion. Fig. 9 shows the manner in which we pile our bolts. Most people who saw our arrangement viewed this particular phase with a certain amount of misgiving. It seemed to them more or less of a hobby, and an expensive one at that, rather than an absolute necessity. It should not be necessary for me to convince you that it is a great deal more economical to pile goods in an orderly way than to throw material helter-skelter into receptacles.

Maximum Visibility. Since we count our stock once a month it is necessary to do the work as quickly as possible and as accurately as possible. Our Stores Department calendar provides

Fig. 9. Method of Storing Bolts.

six days for actual taking of stock. The stock men do this, attending to their regular duties in addition. If materials were piled in a disorderly fashion this could not be accomplished; neither would we get anywhere if the bulk of the stock had to be counted by handling each piece. To count most of our material without actually handling it we designed screen backs for our cases.

Absence of Drawers. As we insist upon counting the materials without handling we did away with the use of drawers. Fig. 10 shows an old case which had 480 drawers. They were used for the storing of very small parts of electrical apparatus. We converted this ancient equipment into modern bins.

Proper Packaging. Contrary to the belief of most operating men it does not cost any more to have vendors ship material in specified containers instead of according to the regular cammercial practice. As far as possible, we make no change from established practice but in some instances we insist on packaging according to our own needs based on the quantities in which the materials are disbursed; for instance, most manufacturers ship line ears, which support the overhead trolley wire, in barrels of

Fig. 10. A Case Formerly Containing Drawers.

from 180 to 220. We insist that they be shipped in boxes of 50.

Armature coils for the rewinding of railway motors we specify in boxes of one set. Small screws which are not of the standard commercial variety we order shipped in packages of 100. and so on down the line.

Everything on Wheels. Economic operation depends on getting the most work done for the least number of man hours expended. Our success in this line may be attributed to the common-sense application of automatic lifting trucks and platforms, which means potentially "everything on wheels."

Fig. 11–15 illustrate our principle—"everything on wheels."

While these appliances are primarily labor saving devices, they tend to prevent accidents.

Fig. 11. Locomotive Crane and Magnet Unloading Car-Wheels.

Fig. 16 shows our traveling hoist which starts from our receiving floor and runs the length of our warehouse.

Fig. 17 shows a device which automatically records the length of wire or rope, ranging in thickness from ⅛ inch to one inch. The apparatus on the right is a standard commercial article and the turn-table on the left is a home-made device.

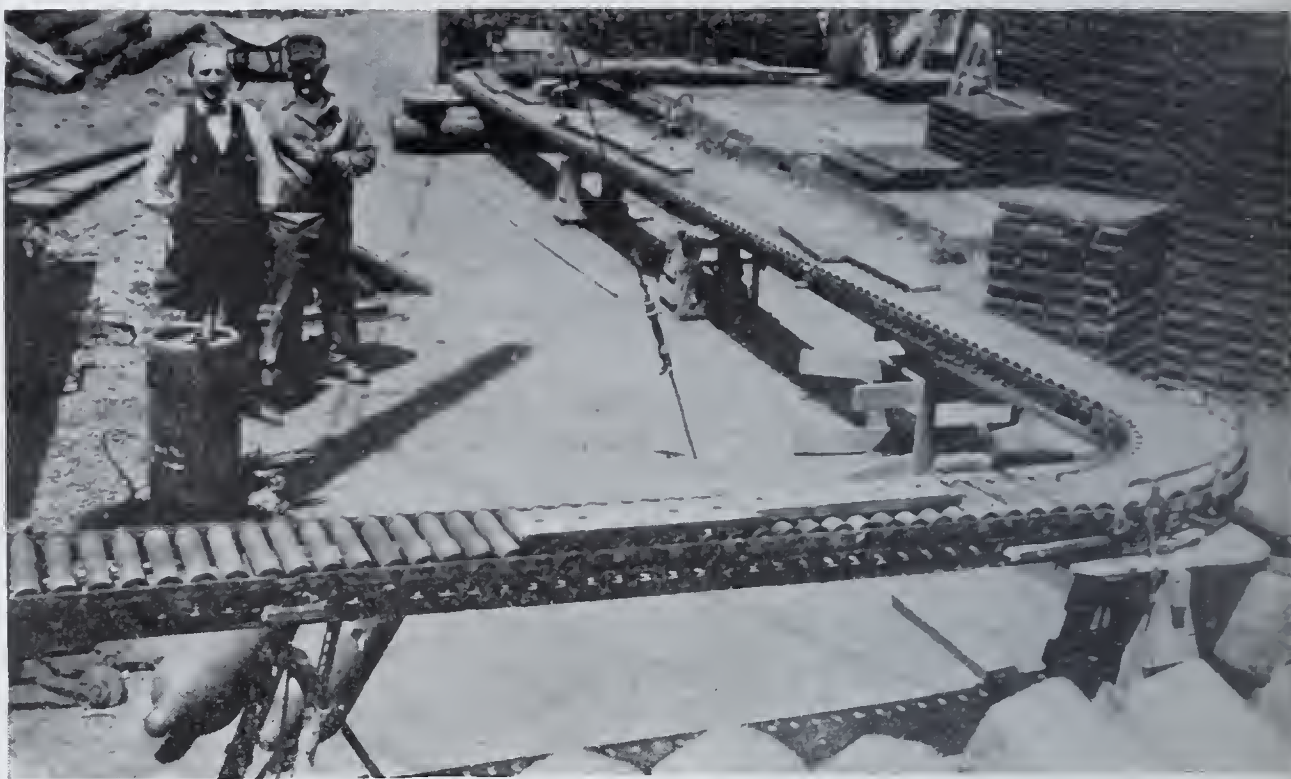

Fig. 12. Gravity Carrier.

Fig. 13. Barrels on Wheels.

Fig. 14. Chain in Platform Boxes.

Fig. 15. Warehouse Trucks, Affording Maximum Visibility.

Fig. 16. Traveling Hoist.

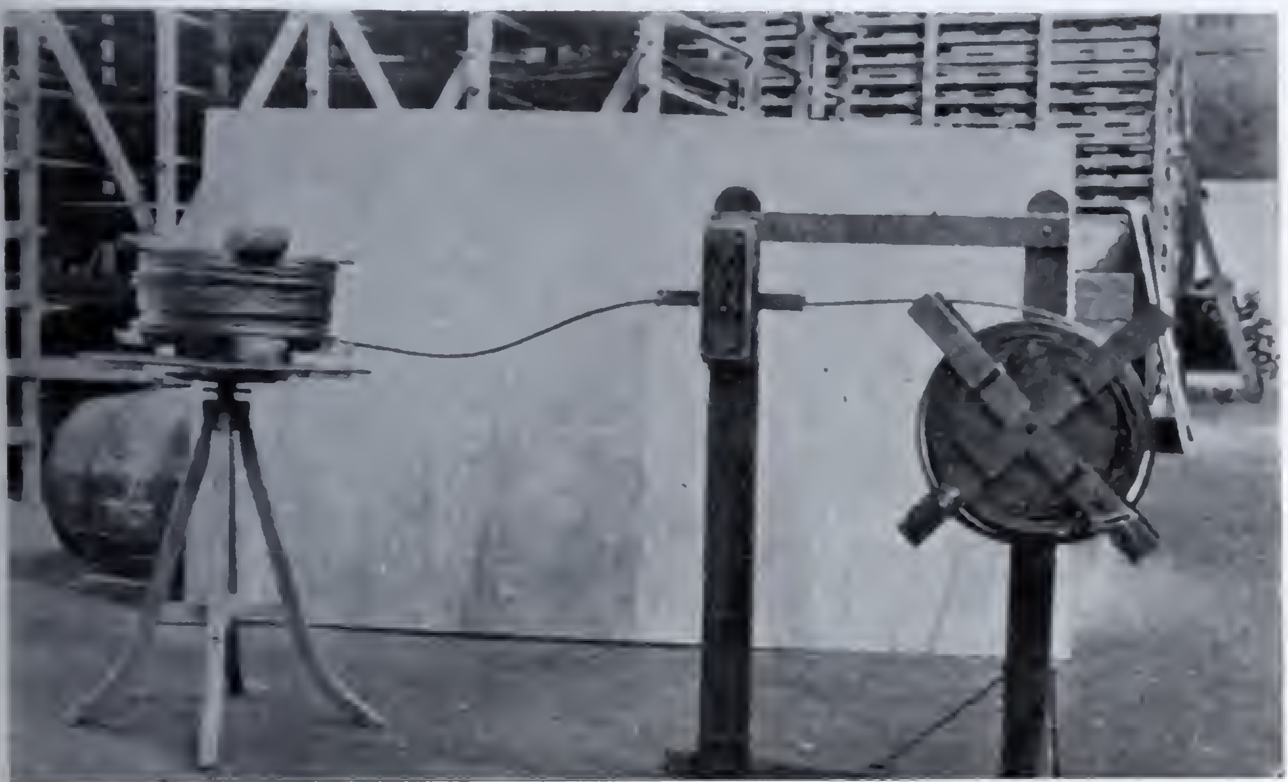

Fig. 17. Wire Reel Meter.

Certain materials, such as sheet-iron, tubing, etc., cannot be properly stored in cases. For this kind of goods, special racks have to be built and since ground space is valuable we have to build them high—sky-scrapper fashion. The portable elevators shown in Fig. 18 are advantageous.

One objection to construction of our cases seems to be the height, which is 11 feet; however, we had to make the most of the space available. We use ladders which are equipped with non-skidding shoes. See Fig. 19.

INVENTORIES

As mentioned before, we count our stock once a month and our annual inventory does not differ at all from our regular stock-taking except that it is taken under the supervision of the auditor. In the efficiency of our inventories we pride ourselves on a standard comparable with the purity of "Ivory soap." Our latest annual inventory comparison, which was compiled by the auditor independently of our records, showed a discrepancy of $1652 which is equivalent to 0.11 of one per cent. of the value of materials handled for the year.

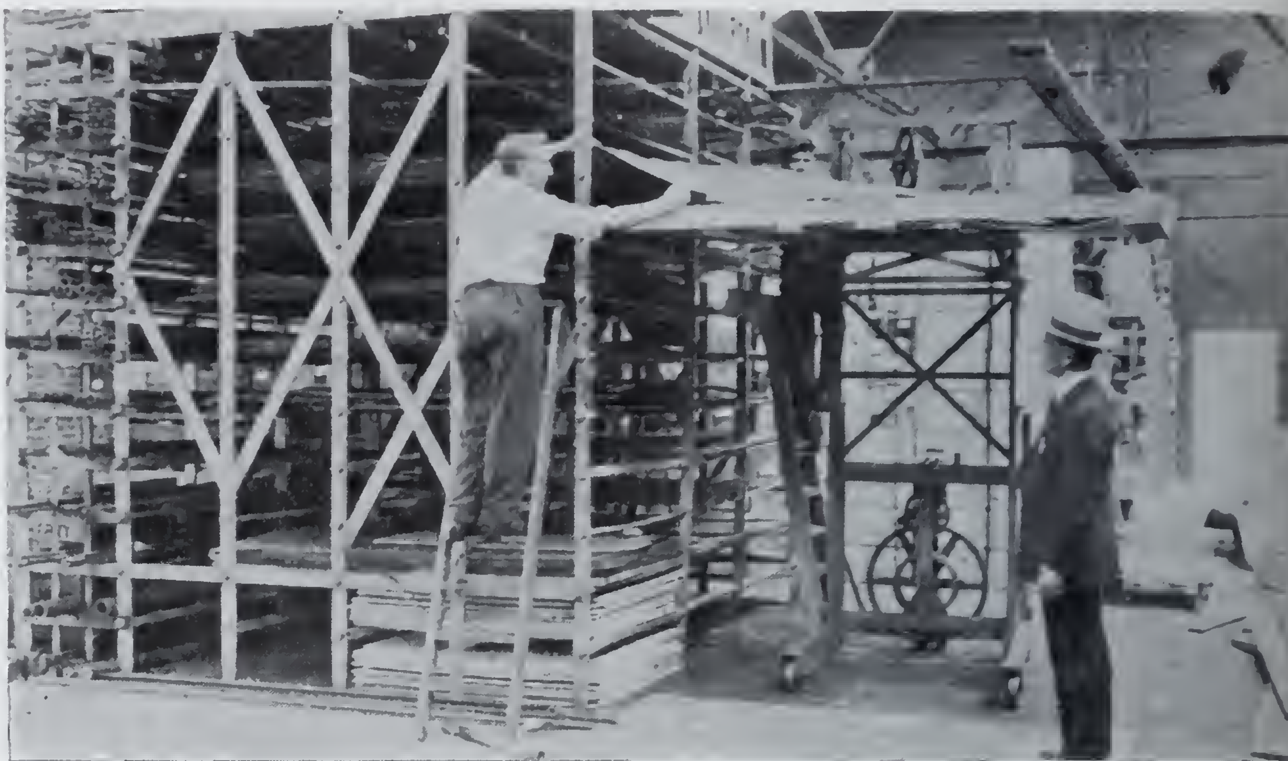

Fig. 18. Portable Elevators.

Fig. 19. Ladders with Non-Skidding Shoes.

RECEIVING

All material for the replenishing of stock is consigned to the general storekeeper. Since the payment of bills depends upon the proper recording of materials purchased, this function is very important.

In the *Electric Railway Journal* of December 21, 1918*, my predecessor† explained how we record materials received. To my mind this system is not at all peculiar to street railway work but can be used to great advantage by anyone who realizes the necessity of an individual tally for each shipment received.

As the material is received, it is examined and if ordered to certain specifications or blue-prints the engineer in charge is notified to pass on the goods. If the specification calls for a certain chemical analysis, samples are taken at random and sent to the laboratory for testing. If it is found that the material does not come up to the specifications, or that it is damaged in transit, it is laid to one side in an enclosure which is called the disposition room. It is kept under lock and key until disposition is made of it.

Articles of small dimensions are tagged, and the tag gives all the information necessary to trace the material to its source. We are very liberal in the application of these tags. It enables the foreman to identify the material properly, and to reorder it intelligently. I might state that every package is opened and material examined; this, of course, does not hold good on standard packages of screws, nails, etc. I also wish to state that we weigh the iron received, by means of a portable scale in our iron rack. In other words, we take nothing for granted, any more than the bank cashier would accept a check before examining the signature.

DISBURSING

The nature of our business is such that 75 per cent. of the materials used is distributed to the various operating barns, with our supply cars running on schedule.

*Vol. 52, pp. 1095–1096.

†Mr. B. J. Yungbluth, since appointed Supervisor of Purchasing and Stores, Philadelphia Rapid Transit Co.

A counter man fills all requisitions for materials emanating from the local shops, while the requisitions for supply-car deliveries are filled by each stock clerk according to the materials he handles.

Fig. 20. Truck Tractor.

Fig. 20 shows a truck tractor which is used for carting materials to and from the shop. It was obtained primarily to cut down the time the men spend uselessly in calling for materials. The subject of delivering materials to shops is an important one and I cannot at present take the time to go into it fully. I will merely say that a centralized store is the answer to this problem—not several stores in a plant. Proper delivery system overcomes the objections to this method.

CLERICAL WORK

STOCK-BOOK VS. LEDGER

Since the replenishing of stock depends primarily on the stores department it is of paramount importance that accuracy shall characterize the factors entering into the determination of quantities ordered. The most important factor is the amount on hand.

The regulating of materials and supplies should be economical and efficient. Our method is based on stock-book records which show the amount on hand with the necessary data as to orders due and received. A very exhaustive description of this method was published by my predecessor in the *Electric Railway Journal*, March 17, 1917.*

By personal experience I find that the stock-book reduces to the minimum the discrepancies between actual stock and record. If any particular factory were to attempt to account for every item in stock the operating expenses would be tripled. No grocer ever retails sugar from a barrel and gets from it just exactly what the barrel contained.

Admitting that discrepancies of this kind would amount to about three thousand dollars yearly, no management would be foolhardy enough to establish a system of cost records which would mean an expense of perhaps five or six thousand dollars a year to enable them to know on what particular items the errors occurred. This is practically what the card or ledger system amounts to.

The conclusions that we draw from our experiences may not be the same that would result from the study of manufacturing conditions but I dare say that for the purpose of replenishing stock and not for accounting, it does not matter if out of a lot of 50,000 cotter keys 481 were lost during a year's business.

Our stock-books are easily read and present a graphic chart of the movement of any materials for a period of two years. It is our one and only record which shows all the factors necessary in ordering materials. The amount on hand at the beginning of the month, plus the amount received during the month, minus the amount on hand the next month, is the quantity used. The use of these books does away with posting disbursements or receipts or cards or in ledgers, and also does away with bin cards which are in vogue in some plants, where dependence is placed on the stock man in charge to deduct the quantities taken out of the bins. The study of the stock-books and the use to which they may be put in every store, whether engaged in manufacturing or

*Vol. 49, pp. 490–492.

transportation, cannot be adequately treated in the time at my disposal, but we claim that the use of these stock-books minimizes the number of shortages.

For convenience, our stock sheets are bound in books of 13 sheets, each sheet having seven items. Only material belonging to one section is put in each book and the contents of the stock-book are indexed on the front of it.

REPLENISHING STOCK

This phase of our operation is considered under the head of clerical work, since the subject has been studied from the standpoint of manual handling.

As soon as the monthly count is made in the stock-book, it is taken over by a clerk who shows the amount due on each item. It is then gone over by the assistant general storekeeper, who indicates in the proper column the quantity to be ordered. With these figures as a basis, the requisition clerk then typewrites the purchase requisitions in three copies. The original copy goes to the general manager, and then to the purchasing agent; the duplicate to the receiving clerk; and the triplicate, which is a card copy, is kept in the open file which, by the way, is also on wheels.

Fig. 21 shows the card form for requisitions.

The top portion of this sheet is divided into five spaces for the days of the month from the first to the thirty-first. Colored tabs are used for each group of days.

The reverse of this card is used for the copies of correspondence so that all matters pertaining to a certain requisition are kept in one place and it is not necessary to dig through half a dozen files to find it.

These requisitions are numbered with a hyphenated number like 915–110, this number indicating that the requisition was made up on September 15. The receipt of each item is shown by the date, the individual receiving the record number, and the quantity. As soon as all materials on the requisition are received it is filed in the closed file.

A great deal of material is hurried by telephone, by wire, or by special delivery letters. All hurry records are shown on the card copy of the requisition. Since a great deal of material is

1-6 7-13 14-20 21-26 27-31

Form G S 127—4m 8-20-w
Adopted 11-12
Revised 12-19

MR. C. W. LEPPER,
General Purchasing Agent

PITTSBURGH RAILWAYS COMPANY

C. A. FAGAN, W. D. GEORGE, S. L. TONE, Receivers

MATERIAL REQUISITION

COPY

Req. No.................

Pittsburgh, Pa.,..............................192......

Req. Written by.................

PLEASE FURNISH THE FOLLOWING SUPPLIES:

Telephone No. ....

Telephone No. ....

Req. No. .... Page ....

QUANTITY			DESCRIPTION OF MATERIALS	Class Number	Purpose	Order Number	Date	VENDOR	RECEIVED			DELIVERY PROMISE
On Hand	Due	Wanted							Date	R. C. No.	Quantity	

AUTHORITY FOR REQUISITION

STOCK BOOK NUMBER AND PAGE TO BE SHOWN OPPOSITE EACH ITEM

SHIPPING ORDER ON ITEM No.

No. .... Date .... 192 ....

Deliver to PITTSBURGH RAILWAYS COMPANY
C. A. Fagan, W. D. George, S. L. Tone, Receivers

Care of ....

At ....

REMARKS ....

REQUISITION COMPLETE

File By ....

REQUISITION CHECKED AGAINST STOCK BOOK By .... and ....

Fig. 21. Requisition Form.

ordered irrespective of our regular demands, the requisitioner (the head of a department) is advised that the material is received for his disposition.

ACCOUNTING

The payment of invoices for materials furnished depends upon whether the material was accepted or rejected. An individual receiving record is used for each shipment, and the invoice shows the date of receipt and the receiving record number as well as the freight bill and the amount.

No material whatever is issued without proper requisition duly signed by the foreman and receipted. These requisitions, properly extended with the current prices, form the basis of charges against the various accounts. Some railroads do this work exclusively in the stores department; others do it through the auditing department. In our company both departments do certain portions of it.

To keep step with the movement of materials, charts and curves are prepared from month to month. The use of curves, however, is not restricted to the movement of materials, but extends to all our activities. One of these curves is shown in Fig. 22.

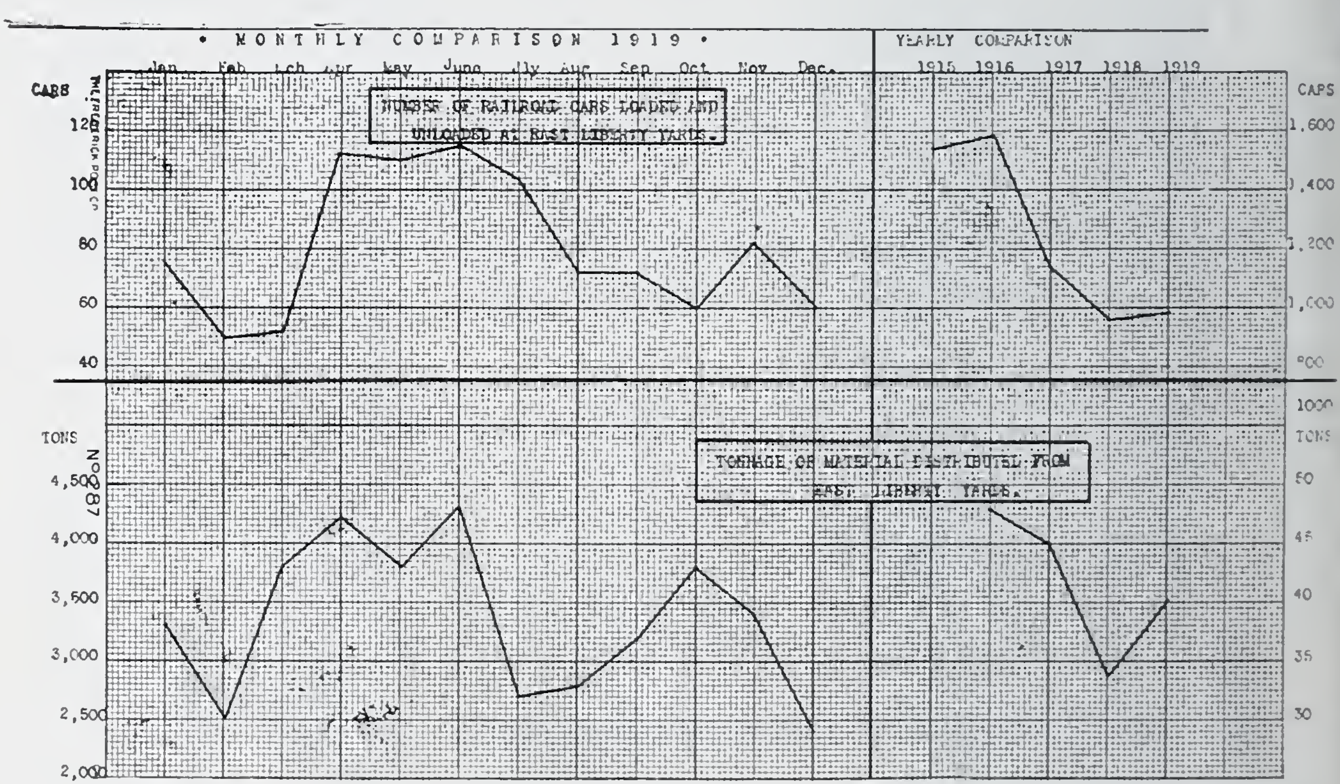

Fig. 22. Curve Showing Trend of Operation.

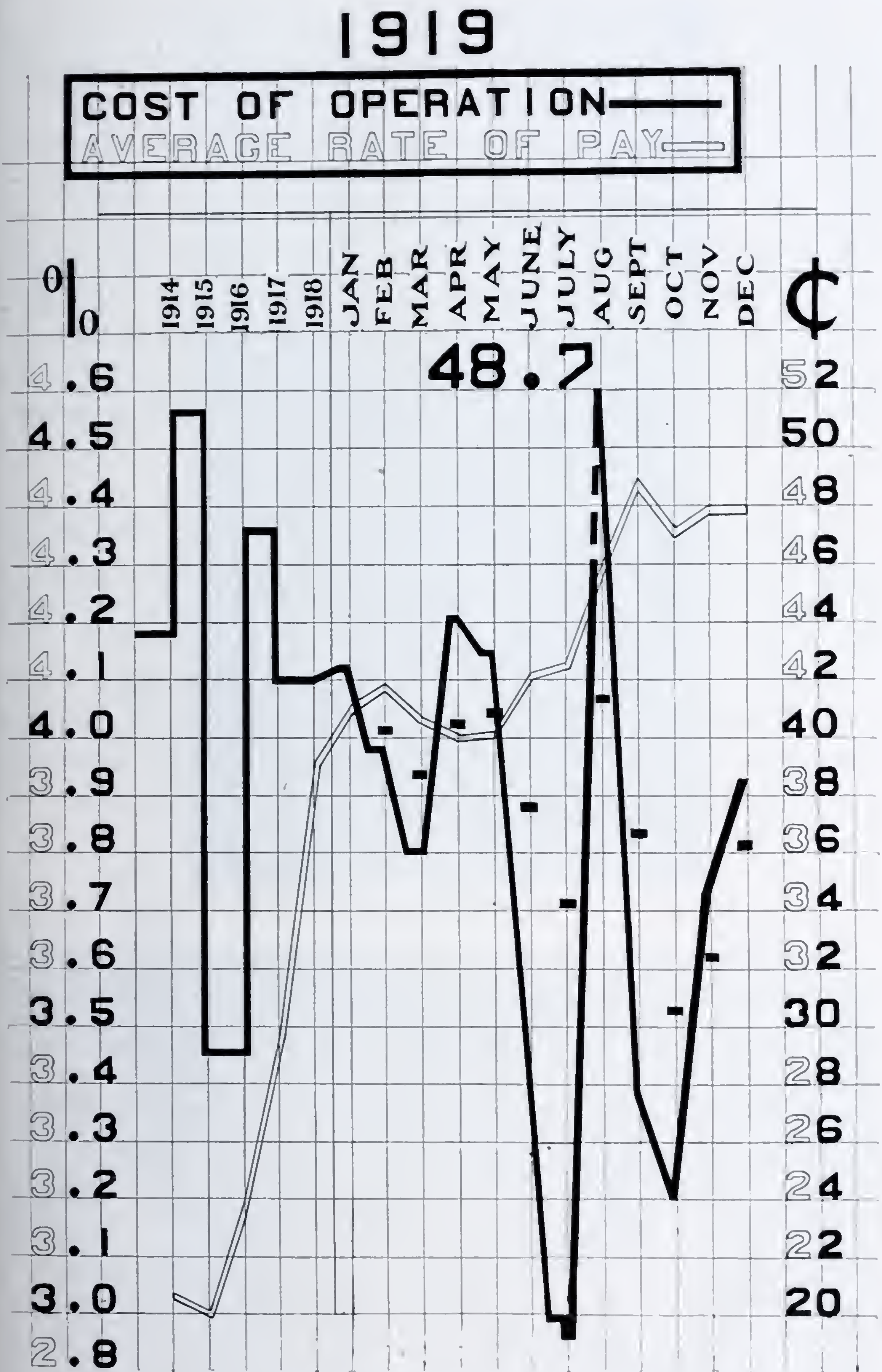

Fig. 23. Cost of Operation, with Average Hourly Rate of Pay.

Fig. 23 is our barometer. It shows the percentage of cost of operation for each thousand dollars' worth of material disbursed, which is based on the amount properly chargeable to stores expense as wages and salaries of the department, rent of storage yard, cost of heat, light, water, truck hire, etc. This chart is displayed in a prominent place all through the year and the boys take pride in achieving a downward tendency in the cost of operation. It also shows the average hourly rate of pay. The good showing evidenced by this chart—even considering the advanced cost of materials as compared with previous years—is due to the pre-arranged plan of operation and the use of labor saving devices.

OBSOLESCENCE

The street railway industry is advancing by leaps and bounds in every department, and this means that new designs in equipment are constantly required. This naturally increases the number of items of stock carried.

Since it is necessary to carry on hand repair parts for all types of equipment, it also stands to reason that at some time certain kinds of repair parts become obsolete. If they cannot be sold or converted into usable parts they are scrapped.

SCRAP

ACCUMULATION

On our property we sell annually many thousands of dollars' worth of scrap. Due to the nature of the business there is a very large accumulation of non-ferrous scrap—principally copper. It is our function to gather up, sort, store, and ship all scrap. Scrap is gathered each time the supply car makes delivery to various points; and, in addition to this, arrangements are made for semi-annual pick ups as shown on the stores calendar. On these pick up trips all surplus materials are also gathered.

STORING

Ferrous scrap is taken to the scrap docks where it is sorted according to kind, and cut into charging-box size, if necessary. For this work, use is made of an alligator shear and a cutting torch. The scrap is then put into bins. See Fig. 24–25. The non-

Fig. 24. Alligator Shears Cutting Ferrous Scrap into Charging-Box Size.

Fig. 25. Scrap Bins.

ferrous scrap is segregated according to commercial practice and is handled at the general stores. The copper is put into shape for melting and when ready for sale is placed on lifting-truck platforms—another instance of "everything on wheels."

SELLING

Old materials rise to new dignity. Any source of income amounting to as much as we derive from scrap sales may readily be considered a business in itself. The opportunities for profit or loss entitle the subject to the greatest consideration. The prices of scrap are perhaps subject to more influences than in the case of any other commodity. General business conditions as well as the scrap market conditions must be followed closely to gage the probable trend of the price curve, as the markets fluctuate daily. It is the custom at some points to dispose of the scrap once a month irrespective of market conditions, or else on a contract for the year based on the fluctuation of new metal. We have found it an additional source of revenue to follow the market.

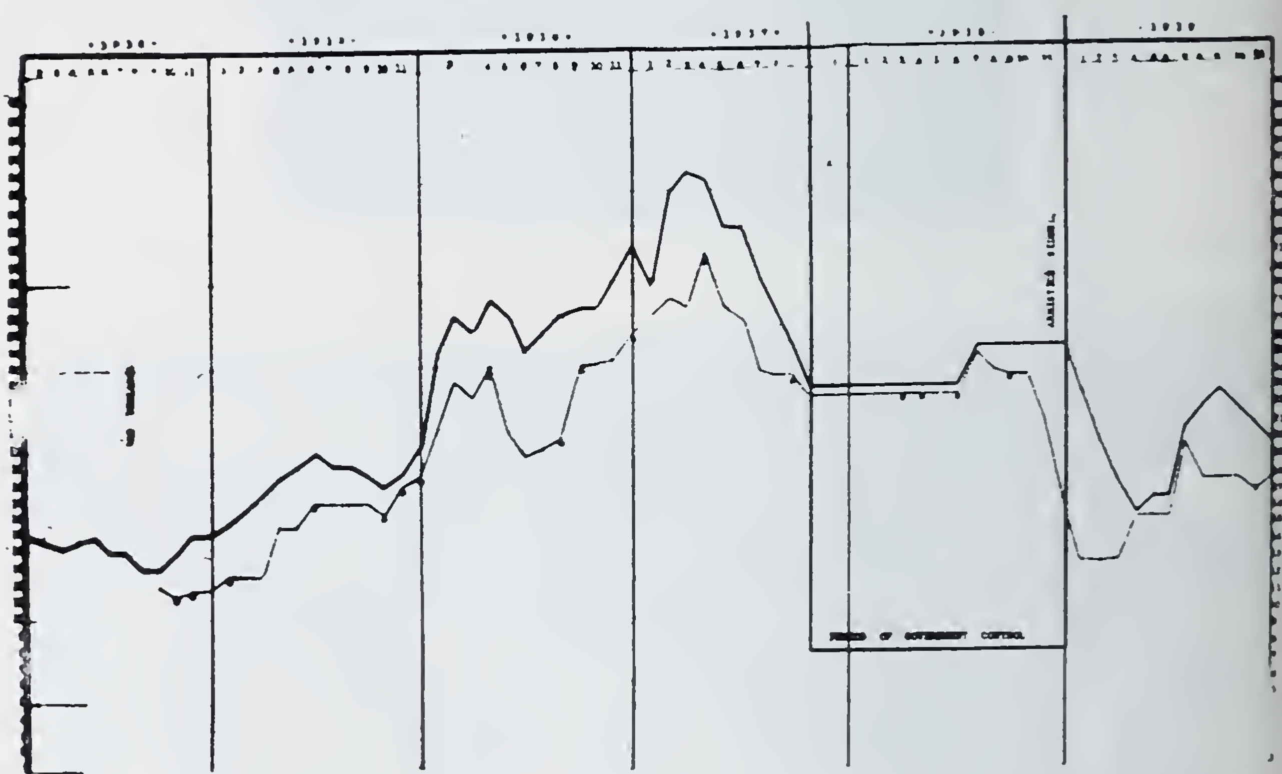

Fig. 26. Comparison of Market Fluctuations for Ingot and Scrap Copper.

Fig. 26 shows the comparison of prices between pure Lake copper and scrap copper by months during the years 1914 to 1919. You will readily see that the differential between the two prices

is very seldom the same throughout the year.

This table also shows the time at which we sold our scrap. We struck it pretty nearly right all through the year.

All scrap is sold to the highest bidder. We have a mailing list of scrap dealers and mills constantly in the market.

We sell our scrap f.o.b. loading point and insist upon cash deposit for the value of each shipment before it is actually forwarded.

SUMMARY

The foregoing remarks by no means exhaust the topic; they merely scratch the surface. The science of stores engineering has not been developed to the fullest advantage. The possibilities of this kind of work are unlimited and it is indeed gratifying to one who has its success at heart to know that the work is beginning to receive recognition.

In a large measure, our success is due to the far-sightedness of our General Manager who provides the requisite labor-saving devices. Credit is also due to all heads of departments who cooperate with us. Recognition is also due to the employees who actually do the work.

After all, stores engineering is a matter of cleanliness and common-sense.

DISCUSSION

Mr. Philip H. Lantz:* I would like to ask one or two questions but before doing so it might be in order, as a comment on the paper, to mention the advantage to others of having the advanced methods used by the Pittsburgh Railways Company, so fully exhibited and described to them. Improvements in detail have been developed through specialization in the field of stores engineering and I should think some experimentation might be saved many interested managers by taking advantage, where adaptable, of what someone else has successfully put in practice. This emphasizes the value of such exchanges of thought as are brought out in a meeting of this kind.

When we consider the stores system just described, it appears that someone must give it constant and capable supervision to make it a success. It looks like a good system; also no doubt it needs punch behind it to keep it moving right. In this respect it is not exceptional but follows the footsteps of everything else worth our best endeavors. From a cold economic standpoint it must pay or it wouldn't be done.

A question occurs to me about the monthly inventory. Is it justified on the basis of cost and results? Another question; why is a card system not used instead of a book system to keep track of stock?

Mr. M. T. Montgomery: Our monthly stock-taking forms an integral part of our scheme of operation as you remember having seen it on our stores department calendar. The stock men in charge of the various sections count the material, therefore no extra expense is involved in doing this. Detailed analyses taken at various periods show that it costs under this scheme 14 cents per thousand dollars worth of materials counted.

Regarding the card system; it is true its use is common in a great many places, but for the purpose of replenishing stock—and by this I do not mean for purposes of accounting—the use

*Financial Assistant to President, Philadelphia Co., Pittsburgh.

of the stock-books localizes the errors and no amount of book-keeping however elaborate can compare with actual results.

Mr. C. N. Haggart:* Mr. Montgomery has enlightened us on a phase of engineering with which many of us, as engineers, are not familiar.

My first experience with stores engineering was with the American International Shipbuilding Corporation at Hog Island. As contributing to the discussion, I might describe briefly one feature of stores engineering work there; namely, the getting of structural steel to the shipways.

All structural steel that came from the fabricators to Hog Island, was stored in its predesignated place in the storage yard. From there it was requisitioned to each way by the superintendent of materials, as needed.

There were two types of ships built at Hog Island, with a separate storage yard for each type. Material as it came in and was unloaded was reported to the head office of the stores and material department. This department allocated the material to the ships in their order and made up a "Powers" card, one for each piece of material, which was sent to the ways. Each morning these cards were run through the Powers machine, for each way separately, thereby typewriting a complete list of material available each day for each ship. These typewritten available lists were furnished to the foremen of the ships, these foremen working in the construction department. When a foreman of a fabricated ship needed certain material, he looked over his available list, and if the material was available for his particular ship he could then requisition it from the storage yard.

Each five ways constituted a yard, and there were ten yards altogether. The stores and material department had an office in each yard with an engineer in charge, with clerks and a Powers machine. The ship foreman's requisition was passed through this office and, as is evident, he could not requisition any material unless there was a card in the office to show that the material was in the storage yard and allocated to his ship. Upon request from the foreman, the stores and material engineer made up a requisi-

*Structural Engineer, Pittsburgh.

tion for material. This was done by putting the proper card through the Powers machine which automatically printed the mark of the pieces, their location in the storage yard, the way to which they were to be shipped, and the position on the way to which they were to be spotted; namely, forward, aft, or one of the two intermediate parts.

This system worked out remarkably well, the greatest difficulty apparently being in getting material delivered to the storage yard.

Mr. J. B. Connally:* I would like to ask whether in making up their requisitions for withdrawals from stores, the operating department requiring the stores sends the requisition to the stores department, and whether they look after the transportation of the material from the stores to the point at which it is to be used in the shop; or, whether they have some system of collecting the requisitions from the operating departments and delivering them to the stores, and the stores department delivering the material to the operating departments. I have in mind the matter of cost involved in handling a large number of requisitions for small quantities, using a mechanic to go to the storeroom for one item of material rather than a cheaper man from the stores department delivering a number of items on a trip to the department requiring the material.

Mr. M. T. Montgomery: The nature of our business is such that fully 75 per cent. of the materials which are distributed from the storehouse are delivered to division stores and outlying barns, shops, etc. These deliveries are made according to a prearranged schedule, each point being visited once a week with our supply car. Materials used in the shop are now being delivered with a truck tractor with trailers. This, by the way, is a recent addition to our equipment, and the shop delivery system has not been perfected.

The aim is to collect the withdrawal requisitions from the shop at certain stated periods of the day, and deliveries will be made accordingly. The purpose is to deliver all materials when

*Manager of Purchases, Mesta Machine Co., West Homestead, Pa.

and where needed, whether in the shops or to any point in the system.

The truck tractor mentioned, was primarily obtained to cut down the expense involved in sending high-priced mechanics for materials—in other words, to eliminate the wheelbarrow proposition.

According to practice which obtained in the past, the scrap is being sold independently to the purchasing agent. The general manager decides when the scrap should be sold to the highest bidder.

Mr. J. B. Connally: That is very interesting in the matter of organization, and a department should work to a main function. The main function of the operating or production department is producing the commodity. The function of the materials department is providing the materials needed to produce that commodity, relieving the superintendent of operation of that side issue which occupies a minor portion of his thought, only—and which is usually neglected more or less—and placing it on the department whose main function is to provide the materials required for the operation of the plant. Personally, I think a great improvement can be made in the matter of putting upon the stores department a real obligation to supply the operating departments with the material they need, by a much cheaper method than they will employ if they have to send their requisitions to the store-room and transport the material to their respective departments. This, of course, would involve the necessary organization and facilities in the stores department.

Mr. D. F. Manice:* Following up the matter of functioning, I want to ask the reason for having the scrap sold by the stores department instead of the purchasing department—a department which is supposed to keep more closely in touch with market conditions, and the function of which is to trade.

Mr. M. T. Montgomery: Our purchasing agent is not in touch with that scrap. He is not out at the yard where the scrap

*Efficiency Engineer, A. M. Byers Co., Pittsburgh.

is kept. The purchasing agent is in touch with the market, of course, and he orders the goods which are requisitioned. As far as the scrap is concerned, the general storekeeper has always attended to it to the satisfaction of the management; therefore there has been no reason to change the custom.

MR. D. F. MANICE: The purchasing agent is generally much more in touch with conditions. If the stores department tells the purchasing agent the scrap is to be sold, it is up to the purchasing agent to dispose of it or trade it off to the best advantage of the company.

MR. M. T. MONTGOMERY: In our organization we merely take care of the scrap and see that it is arranged, and then it is the general manager who decides where we shall sell. We have to take our bids to the general manager, and the man who bids the highest for the material is the man who gets it.

MR. WALTER G. SCOTT:* Does your purchasing agent inform you of the fluctuations of prices from time to time on various commodities you buy so that you will know when to send in your requisitions for quantities of material?

MR. W. E. BITTNER:† It is my belief that if the stores department keeps in touch with market conditions, as also does the purchasing department, unnecessary work is being done. My idea of the stores department is that it should see that proper stocks are maintained, and should advise the purchasing department what quantities are used over any period (this applying principally to repair parts and all standard items, quantities of which are used at all times) and the purchasing department should use its judgment as to what quantities should be bought.

MR. M. T. MONTGOMERY: I consider the replenishing of materials as one of the main functions of the stores department. This replenishing is done by requisitioning for materials based first, on regular requirements; second, on seasonable requirements; third, on special requirements.

*Purchasing Agent, R. D. Nuttall Co., Pittsburgh.

†Assistant Purchasing Agent, Diamond Alkali Co., Pittsburgh.

The purchasing agent—while it is true that he keeps in close touch with the market—has absolutely no way to tell when, and how much of, certain materials are necessary for the upkeep of the road. When purchasing materials, he depends fully on our requisitions. If, in his estimation, at certain times the market is propitious for buying certain standard materials, he tells us so; we consult our records and, if it is found that certain materials will be needed in great quantities, we requisition for them, specifying protracted deliveries. We do this on our own initiative a great many times, considering market conditions and possible delays incidental to transportation.

MR. H. M. SCHMITT:* In reference to scrap material, we have 27 store-rooms or operating units, scattered over a wide territory. The entire accumulation of scrap, and obsolete or second-hand material is reported to the purchasing department by a card system which indicates complete information as to quantities, classification, condition, etc. The disposition of these materials is entirely under the jurisdiction of the purchasing department. It has been our experience that a better average return is secured by handling it in this way than if left to the various storekeepers to dispose of any part of it locally. There are, of course, exceptions to this, but where sales are made locally the storekeeper must first obtain permission from the purchasing department.

MR. M. T. MONTGOMERY: No scrap is sold direct by the general storekeeper.

MR. E. W. PITTMAN:† Does the store perform the functions of a tool-room? Does it issue any tools or materials that are subject to return after the completion of the work for which they are issued?

MR. M. T. MONTGOMERY: Our stores department does not perform the function of a tool-room. We insist, wherever possible, on the return of an old tool for a new one withdrawn.

*Expediter, Purchasing Department, American Sheet & Tin Plate Co., Pittsburgh.

†General Manager, Dravo Contracting Co., Neville Island, Pa.

Mr. C. H. Edwards:* I would like to ask you if, in giving out supplies to different departments, your store-room demands a requisition for each article, signed by the foreman of that department; and whether, in case the foreman is not to be found just then, they give the material out to the workman? Do you keep a daily record of all material leaving the store-room, the department to which it goes, and the job on which it is used?

Mr. M. T. Montgomery: We demand a requisition for all materials withdrawn. Although we do not insist on the personal signature of the foreman, we have enough confidence in him to know that he will not delegate such an important function to any person who is not trustworthy.

We do not keep a daily record of materials leaving the store-room. The requisitions on which the withdrawals were made form the basis of our accounting.

Mr. A. E. Lang:† Mr. Montgomery said that in using the card system it all depends on the record clerk to keep the card properly posted. He no doubt had in mind the bin card used in some store-rooms. That is not the system used in our plant. We have all material numbered. These numbers are known as commodity numbers. For each commodity we have a card showing the description of the material, maximum and minimum, and commodity number. This card is ruled on both sides. On the front we have one space for material on order, and one space for material received, and the rest of the card is spaced off for disbursements. These cards are kept at the office. The material is disbursed only on requisitions properly filled out and signed by the person authorized to do so. The man who fills the requisition puts on the requisition the commodity number which he gets from the bin tag, and then stamps it with a numbering machine. Each morning the requisitions taken the previous day are taken to the clerk doing the posting. He puts them in numerical order to make sure none is being held out or lost, and also to give him a correct count of requisitions filled. In posting, he catches any error—such as the wrong commodity being placed on the requisition—and if during

*Storekeeper, Fort Pitt Malleable Iron Co., McKees Rocks, Pa.
†General Storekeeper, Mesta Machine Co., Pittsburgh.

the posting he finds a card that shows the material has reached the minimum, a record is made on a list kept for that purpose. One of the attendants counts the material in the bin and puts the amount on the list, and if the amount on the stock records agree with the amount actually in stock the clerk passes the card to the chief clerk who orders the material, posting in the material ordered column the amount he ordered, and the date he ordered it. This requisition is sent to the purchasing department which buys the material and sends the stores department a copy of the purchase order. The clerk then posts in the material ordered column the amount ordered, the purchase order number, and the date ordered; and, while posting, the clerk can see at a glance whether the proper amount has been ordered, also how much time has elapsed from the time the requisition was sent them until the material was ordered. Then, when the material is received, a copy of the receiving report is sent to the stores department, posted in the material received column, and carried in the balance column, giving exactly the amount in stock.

After the material reaches the minimum and is counted, if an error is discovered, the clerk traces back to see if an error in posting has been made. If he finds one, he corrects it. If not, he must make an adjustment, either crediting or charging the inventory adjustment account.

How long do you think inactive material should be carried before it should be considered obsolete?

What advantage has the ledger or book system over the card?

Mr. M. T. Montgomery: Lack of time prevents going into every detail explaining the advantages of the stock book over the stock card or the ledger. I might repeat that for the purpose of replenishing stock we do not wish to depend on any theoretical records and since multiplicity of entries increases the liability of error, it stands to reason that no theoretical stock balance will ever agree with actual conditions.

We list materials that have been inactive for a period of two years and forward such lists to the head of the department interested, relying on his good judgment for the ultimate disposition. This involves either the selling or scrapping of the material.

MR. C. A. HARRIS:* I would like to amplify Mr. Montgomery's answer. As far as obsolescence of materials is concerned you cannot take anything for granted. We would not take our own judgment. We list materials that have been inactive for two years, consult the engineer in charge of the work and accept his decision.

MR. CHARLES F. GRAY:† In placing requisitions for standard commodities such as machine bolts, nails, washers, pipe fittings, screws, etc., do you state on the requisition how long the material ordered will last—that is, one month, two months, etc.? If not, does the superintendent who approves the requisitions have any way of knowing how long materials will last? Does the purchasing agent have this information? If not, how can he take advantage of market conditions? Do you specify on requisitions either the date of delivery for which material is required, or the date material should be shipped?

MR. M. T. MONTGOMERY: We do not state on any requisition how long materials will last, as in our business that is merely a matter of conjecture. In a great many cases we give a delivery date on which material should be shipped.

MR. C. A. MOEKLE:§ Does the stores department order all material used for every operation? If you are going to order some material peculiar to one job, or certain equipment, does that all go through the stores department, or is it ordered by the operating department directly, for that particular job?

MR. M. T. MONTGOMERY: We order, receive, store, and deliver all materials needed in the operation of our road with the exception of special tools or goods required for emergency repairs.

*Assistant General Storekeeper, Pittsburgh Railways Co., Pittsburgh.
†Chief Storekeeper, National Tube Co., Ellwood City, Pa.
§Cost Accountant, Dravo Contracting Co., Pittsburgh.

REGIONAL PLANNING IN THE PITTSBURGH DISTRICT

By Morris Knowles* and Maurice R. Scharff†

INTRODUCTION

History. The planning of regions is the newest outgrowth of the art of town planning. Just as it became recognized that the "City Beautiful" could not be the sole aim of town planning, and that the comfort, convenience, health and efficiency of city life required that it be provided with adequate facilities, developed in accordance with previously prepared plans; so it is now apparent that it is no less vital that the regions, which constitute the environment of cities and towns, must be planned also in harmony with the conditions within the towns, if these communities are to be mutually helpful instead of harmful.

In Pittsburgh, the idea of regional planning is a new one, as a definite, conscious ideal; and yet it must have been somewhere in the background of the public mind throughout all the many years during which the improved organization of the municipalities in Allegheny County has been under discussion. For the agitation which we have heard since the announcement of the latest census figures is not new.

It has interested the writers very greatly to recall that almost exactly ten years ago (in December, 1910) a meeting of citizens was held in the Chamber of Commerce, at the call of the Mayor, at which the following resolutions were adopted:

> "Whereas, the recent census, which showed a small and disappointing increase within the city, and a larger increase in the surrounding community; and other indications, point to the fact that Pittsburgh's progress had been retarded and that it does not now occupy its rightful place among the cities of the country; and,
>
> Whereas, if the community of Pittsburgh is to successfully solve its greatest problems, including smoke prevention, water supply, sewage disposal and street car facilities, the effort must be made along broad and metropolitan lines and following a general and comprehensive scheme; and,

*President, Morris Knowles, Inc., Pittsburgh.
†Vice-President, Morris Knowles, Inc., Pittsburgh.

WHEREAS, the highways, parks, play grounds and public buildings are community questions and in order to achieve their full purpose, should be located with reference to each other and with reference to the distribution and convenience of population; and,

WHEREAS, annexation by piecemeal, as has been the case in the past, is costly and unsatisfactory and can only result in a badly formed and inconvenient city; therefore be it

RESOLVED, that the citizens present at to-day's meeting form themselves into a 'Greater Pittsburgh Association,' for the purpose of having an annexation bill passed at the approaching session of the legislature."

The same emphasis upon "the rightful place" of the city, as measured by its population, as is sometimes heard to-day, may be noted. But it is also worthy of attention that the better solution of our metropolitan problems, relating to smoke prevention, highways, parks, playgrounds, and public buildings—that is, our problems of regional planning—was also urged as a reason for improved organization of the district.

It is true that "forcible annexation" was the one method of organization which at that date seemed possible of accomplishment. Happily the annexation bill in the 1911 Legislature was defeated by the local patriotism and organized opposition of the boroughs. But even in those days there was a glimmer of the light which has since come, and in the minutes of one of the sub-committees of the Greater Pittsburgh Association, of which one of the writers had the honor to be chairman, it is recorded that, at a meeting held February 4, 1911, "the question of having legislation passed, enabling the county to build a sewage disposal plant, and the metropolitan district idea were also brought up." This perception of the truth has grown to-day until there is a general understanding that "forcible annexation" is undesirable, and a belief that some better form of co-operation, based upon mutual confidence and self determination, can be worked out. It is to be hoped, therefore, that the regional planning movement of 1920 may lead to more helpful results than did that of 1910.

In passing, it may be of interest to note that we can go far back of 1910 and still find evidence of the recognition by thoughtful citizens that the need of regional planning could not fail, at some time, to bring about a better co-ordination of municipal

functions. Thus, in "The Mayor of Pittsburgh vs. The Pennsylvania Railroad Company" (48 Pennsylvania State Reports, 360) Justice John M. Read, of the Supreme Court wrote, in 1864, the following:

> "The time cannot be far distant when public convenience will force Pittsburgh and its sister city, and their surrounding boroughs and municipalities to consolidate themselves into one great system, governed by one municipal legislature and one Executive head. Its citizens will then regard with astonishment the local jealousies of the North and South banks of the two streams which here unite and form the great river Ohio."

The Engineer's Part. In these past discussions individual engineers have interested themselves from time to time in special technical problems, but engineering organizations have failed to play the part which the experience and training of their members would have justified. This was in accordance with the narrow, technical traditions of the engineering societies of that day. But all this is changed now. The engineer of to-day is beginning to realize that his special qualifications impose upon him a special civic obligation, and the recent activities of this Society in local public affairs show clearly the intention to take the lead in matters which, like regional planning, involve so much engineering. No better demonstration of that intention could be had than this splendid attendance on so inclement a night, to discuss the subject which we have before us.

Planning Commissions. One of the earliest attempts to consider community planning in its broader aspects in the Pittsburgh District was evidenced by the creation and work of the Civic Commission, appointed by Mayor Guthrie, January 16, 1909. A table of contents for a city plan was prepared by F. L. Olmsted, John R. Freeman, and Bion J. Arnold, engineers, who were called in to advise with this body of civicists. The breadth of view of the Commission was well expressed in their statement of purpose, as follows:

> "To plan and promote improvements in civic and industrial conditions which affect the health, convenience, education and general welfare of the Pittsburgh Industrial District, to create public opinion in favor of such improvements, and thus to establish such living and working conditions as may set a standard for other American industrial centers."

Both the new conception of regional planning, and the interest of the engineering profession therein are further shown by our official planning commissions. The City Planning Commission established under the authority of the Act of June 10, 1911, was granted jurisdiction, with respect to review of allotment plans, over a belt three miles wide, lying outside of the city limits. The County Planning Commission, established by resolution of the County Commissioners in January, 1919, has extended its interests to the entire county.

In both of these cases, engineers have been chosen as the secretaries or executive officers, while other engineers have been engaged as expert advisers. And this Society, as well as other local engineering organizations, is now co-operating, through committees, in the study of the City Planning Commission's draft of a zoning ordinance.

Citizens Committee on City Plan for Pittsburgh. Still more recently, in 1919, a group of patriotic Pittsburghers have banded themselves together, as the Citizens Committee on City Plan for Pittsburgh to promote the city plan idea in Pittsburgh. From the beginning, this committee has recognized the necessity that all planning studies shall cover not only Pittsburgh proper but the entire metropolitan area of which Pittsburgh is the center. And, as in the case of the official commissions, the committee has not only retained engineering advisers but should receive the hearty co-operation of all the local engineering organizations.

There are also, and always have been, committees of the Civic Club of Allegheny County, the Pittsburgh Chamber of Commerce, and the boards of trade, which have jurisdiction and interest in the community planning movement.

Present Status. Opinion in the Pittsburgh District, then, may be said to be crystallizing rapidly around recognition of the common interests of the community, and of the need of improved planning and organization for the purpose of securing increased efficiency in public service, and incidentally for greater civic prestige. Regional planning is recognized to involve the planning and regulation of the physical facilities of urban district life. It is, therefore, the administrative side of government that is in-

volved, and a solution may be sought which need not necessarily affect greatly its legislative, judicial, and political functions. It is in the light of these conceptions that the problem of regional planning in this district may be taken up, with a reasonable hope of a successful solution.

DESCRIPTION OF THE DISTRICT

The Pittsburgh Metropolitan District cannot be defined exactly, as it has no official status, and as its boundaries would differ somewhat according to the purpose for which it was being districted. In general, however, it might be expressed as all of the territory lying in the valleys of the Ohio, Allegheny and Monongahela Rivers and their principal tributaries, such as the Beaver, Youghiogheny, and Kiskiminitas, or along the trunk-line railroads, and so located with respect to contiguity and topography, as to be possible of metropolitan development within say 100 years or more.

Such a district would be necessarily somewhat indefinite in extent, but, in general, it would include most of Allegheny County, and parts of Butler, Beaver, Washington, and Westmoreland Counties. It would have an area of somewhere between 500 and 1000 square miles, and a population of between 1,000,000 and 1,250,000 as compared with Pittsburgh's area of 42.5 square miles and its population of 588,193. A good idea of the diversity and ruggedness of the Pittsburgh District can be obtained from the relief map shown in Fig. 1. Owing to its indefiniteness, it is difficult to give any description of the district. But some facts regarding Allegheny County, as compared with Pittsburgh, may be taken as sufficiently applicable to illustrate the comparison.

Allegheny County has an area of 725 square miles, as compared with 42.5 square miles within the city. Its population in 1920 was 1,184,832, as compared with 588,193 in the City.

Constituting what is probably the second greatest industrial district in the country (the New York district being first) the county carried on, in 1920, 238 kinds of industry, employing 221,000 men and women, and producing a total of approximately $1,900,000,000.

All of these industrial activities, and the lives of the human

Fig. 1. Relief Map of Pittsburgh District.

beings who contribute to them, were served by 600 miles of steam railroad, 700 miles of electric railway and over 1100 miles of paved streets and highways. (There are 582 miles of paved streets in the city proper.)

About 75 miles of navigable rivers might be considered as belonging within the district. The city alone has 15 parks with a total area of 1304 acres, and the Pittsburgh water-works supplies about 130,000,000 gallons a day through 760 miles of mains. Similar figures are not available for the district or the County, but there are numerous parks and a large number of water-works systems located in the district, without any relation to each other, just as there are a large number of sewer systems discharging through hundreds of outlets which were never planned in relation to one another.

All of these complicated physical facilities and many others, are controlled by a great number of private corporations, subject to a greater or less degree of regulation by the state; or by one or more of the agencies of the state, which exercise jurisdiction within the district—including the County of Allegheny, the second-class city of Pittsburgh, the third-class cities of McKeesport and Duquesne, 70 boroughs, 21 townships of the first class, 35 townships of the second class, and a number of different school districts. Small wonder, then, that these facilities have failed to be planned as units; that conflict, duplication, inefficiency and waste exist; that confusion surrounds the whole problem; and that the average citizen should be at a loss to know where to start in order to bring order out of this chaos.

ADVANTAGES OF REGIONAL PLANNING

After this preliminary discussion, it is perhaps unnecessary to point out the advantages of regional planning. The growing concentration of population, which has led, according to the last census, to more than fifty per cent. of the population of the United States residing in communities of 2500 population, or over, has already impressed upon everyone the vital importance in modern life of the facilities that go with the modern city. But even more striking has been the fact that, from 1900 to 1910, the population of the 25 cities in North America, with more than

200,000 inhabitants, increased 33 per cent.; while that of the districts lying outside but within 10 miles of the cities, increased 43 per cent.; and that, for the decade from 1910 to 1920, an even greater ratio of suburban to city growth may be anticipated from figures already available.

It is evident, therefore, that the time has passed when the city can plan its plant and equipment without regard for the satellite communities that crowd around it. This truth is too self evident to require demonstration, and yet it may be worth while to refer briefly, in passing, to some of the specific advantages of regional planning.

Mutual Effect. The first of these is the mutual effect of conditions in communities which adjoin one another. We reside in the surburban town, and go to our daily work in the central city; industries in one municipality draw their working force largely from another; stores in the city trade with all the surrounding communities, and their salesmen and delivery trucks are constantly circulating throughout the district; improved transportation and highways and the automobile have enlarged the social horizon of every individual and cause a constant interchange.

The citizens of each community are affected, therefore, by the conditions in all. A bad water-supply in one suburb may cause sickness throughout the district; an epidemic in one town may spread to all its neighbors. A deficient police force in the city may permit hold-ups of citizens from all surrounding towns.

So too with the benefits. Parks and public buildings become the playground, not alone of the municipality that provides them, but the entire area. Art museums instruct and elevate, and municipal band concerts entertain, those who come from all over the territory. Every citizen, therefore, comes, in time, to feel the effect of conditions in neighboring communities as well as in his own.

Conservation of Resources. A second advantage of regional planning lies in the extent to which it permits conservation of natural resources—particularly of those resources represented by flowing and underground waters. The quantity of water available for the various uses of a region is strictly limited, and, if the

greatest good is to be obtained from it, not only must the needs of all the municipalities involved be considered, but study must also be given to all the uses to which the available supply might be put, including water-supply, sewage disposal, hydro-electric development, irrigation, water transportation, etc.

Economy. A third advantage of regional planning is economy in construction and operation of public works. Within reasonable limits, large-scale production pays, in public service as it does in industry, because it reduces overhead cost per unit of product.

Efficiency. Finally, regional planning and organization permit simplification and increased efficiency of administration, through doing away with the duplication, conflict and complexity which now result from a number of bodies performing similar functions within the same region. And thus something may be contributed to the relief of the voter from the complexity of his political duties, and to the general improvement of the workings of democracy.

Political Morality. Entirely apart from these engineering and economic considerations there are sound reasons of what may be called political morality for the co-operative solution of such problems. None of us "liveth to himself," and city and suburbs are "all members one of another." As has been pointed out, we are mutually interdependent, and such a relation involves mutual obligations. It is dishonest to enjoy benefits without paying part of the cost; just as it is unfair to be subjected to disadvantages without having the opportunity to assist in eliminating them.

PROBLEMS AND EXAMPLES OF REGIONAL PLANNING

The problems of regional planning and the methods available for their solution may best be illustrated by a number of examples. Some of these will be passed over with little more than mention, but in each case the attempt will be made to point out the relation of the particular problems to the general subject of regional planning, and to the Pittsburgh District; and to show the advantages of regional as compared with local solutions. Among the prob-

lems referred to will be the study of the geographical and industrial characteristics of the region; the development and interconnection of steam, electrical, and water transportation; the arrangement and construction of main highways, boulevards and parks; joint water and sewerage systems; the supply and distribution of electric light and power; smoke regulation; public health; and police protection.

Survey. The first requisite of a regional plan is a comprehensive survey of the topography, geography, population, natural resources, agriculture, industry, and trade of the region—much of which is an engineering study; and one result of such investigation should be a complete topographic map of the area, which may serve as a base map for the regional plan. Not only should this map show the topography and locations of towns, railroads, streams, canals and other natural and structural features; but the data on natural resources, agriculture and industry should be correlated with it, in such a manner that maps may be prepared showing the relative distribution of all the factors affecting the life of the region.

The recognition of this fundamental prerequisite by the Citizens Committee on City Plan for Pittsburgh is demonstrated by the time and expense it has put, at the beginning of its work, into the preparation of complete and improved maps, not only of Pittsburgh proper, but of the entire metropolitan area. These maps include a base map, recording all of the basic survey data available, upon which accurate maps may be based; a topographic map; a population spot map, showing distribution of population; a highway map; a transportation map, etc. Illustrations of types of these maps are shown in Fig. 2 and 3 (inserts).

Railroad Transportation. Railroads are the arteries through which the life blood of our country's trade flows. Fortunately, the considerations relating to natural resources, most favorable location of industries, and movements of population which should mold the regional plan have guided the self-interest of those who have been responsible for the development of our railroads up to the present day. But while this is generally true, it does not apply universally, and selfish interest has sometimes diverted development to lines less well adapted to the public interest. Moreover,

Fig. 2. Section of Pittsburgh Metropolitan District, Showing Basic Data and Arterial Highways.
(Prepared for Citizens Committee on City Plan for Pittsburgh.)

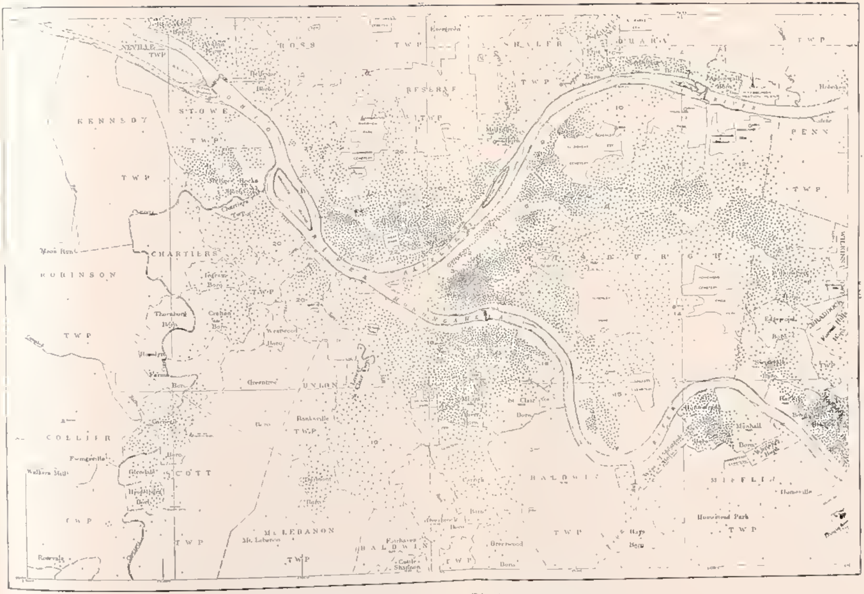

Fig. 3. Section of Pittsburgh Metropolitan District, Showing Basic Data, and Distribution of Population. (One Dot = 100 Persons).
(Prepared for Citizens Committee on City Plan for Pittsburgh.)

our past theory of regulation by the maintenance of competition and the prohibition of pools and traffic agreements has itself compelled development, in some instances, in ways which would not have been dictated by wise forethought and regional planning.

Regional planning must take into account the fact that railroads are best adapted for long-haul, through traffic. It must, of course, be based upon the existing railroad systems, and must provide yards and terminal facilities, both for facilitating through movement and for convenient transfer to local short-haul roads and to electric and water transportation routes. The study of electrification must be continued in connection with the elimination of noise and dirt in our cities, and with the general power program for the region in which the railroad is located; and a new type of organization and regulation must be found which will at the same time protect the public interest and encourage the development of the railroads so as to serve the needs of industry.

Here in Pittsburgh, intelligent self interest has developed the railroad facilities so as to serve industry with reasonable efficiency. But this does not mean that all the possibilities of regional planning have been attained. The problem of an adequate union station, and of convenient transfer from one system to another so as to secure the greatest benefit from all roads, remains to be worked out in future. We are but on the threshold of the problem of railroad electrification, which public convenience and the cost of transporting fuel are bound to bring eventually; and the provision of joint terminal facilities and belt lines to permit the greatest use of our rivers for water transportation, remains almost wholly untouched.

Electric Transportation. The electric railways are the natural complements of the railroads. Admirably adapted for short haul and interurban traffic, they should be developed along with, and not in competition with, the trunk railroads. The growth of urban life requires more and more that city workers shall live in outlying districts and depend upon cheap and rapid transportation to go to and from their work. And a great field for short-haul freight carriage of agricultural products from the farm to the neighboring city, or steam railroad terminal, remains only par-

tially developed by interurban roads. The regional plan should recognize the distinct function of the electric line in the transportation service of the region, and should provide the program for its performance of that function best fitted to the solutions adopted for the other problems of the region.

Private enterprise in the Pittsburgh District, has founded a comprehensive system of electric transportation which serves almost all parts of the district. No one, however, could call its present service or its physical or financial condition satisfactory, and regional planning for the future is still an urgent need, so that extensions may be built as required to care for the future population which continued industrial growth will make necessary, and so as to avoid the mistakes which in the past have resulted from direction of development in the interest of private profit instead of regional benefit.

Water Transportation. One of the striking things brought out at the time when the war threw its peak-load upon our railroads was the help which might have been obtained from our rivers and canals, and the extent to which we were unprepared to utilize them. This lesson will not be forgotten, and improvement of waterways may be anticipated on a far more extensive scale than ever before. It is to be hoped that such improvements will not continue to be made upon the basis of the "pork-barrel" methods of the past, but that rational regional planning will establish the true function of water transportation, in combination with steam and electric lines, and will provide a reasonable program for the development of our transportation system as a whole.

Such planning, also, will recognize more clearly than ever before the necessity of interconnection of these various types of transportation routes—of building joint terminals, with adequate wharves, docks, warehouses, railroad yards, cranes, and electric facilities, so that the transfer and trans-shipment of passengers and freight may be accomplished most economically and most efficiently and so as to secure the greatest usefulness from the combined system.

The application of these remarks to Pittsburgh may be strikingly illustrated by comparing a picture of the wharves at Pitts-

Fig. 4. (Top) Monongahela River—Water Front at Pittsburgh. (Bottom) How Paris Appreciates the Value of Its River Frontage.

burgh with one of any of the great ports of the world. See Fig. 4. Adequate port facilities located at a point chosen by engineering judgment, and equipped with suitable railroad connections and with modern appliances, would serve the entire Pittsburgh District. Such facilities, therefore, could properly be built and maintained through the co-operation of the entire district.

Main Highways. If the railroads are the arteries of trade, then the highways are the capillaries through which the individuals engaged in it receive the blood which quickens their lives. The amount of wealth which is produced and which cannot be placed upon the railroad, without the intervention of a haul by wagon or truck, is vast. The life of agricultural communities is wholly dependent upon highway transportation, and the growing use of automobiles and trucks, and the development of interurban vehicular traffic, give highways more importance than ever before. This is recognized throughout our country, as is witnessed by the development of the "Good Roads Movement," which is responsible for the construction of hundreds of millions of dollars' worth of highways now under way, or planned.

Regional planning, however, cannot permit the highways of the future to be located and constructed as have been many of those of the past. Main roads will no longer be located with reference to section or property lines, but with reference to topography, the distribution of products creating traffic streams and the co-ordination of the highway system with the railroads, electric lines and waterways. Types of construction will be carefully adapted to traffic needs—not only as to road widths, but also as to gradients, surfacing and drainage.

The importance of these considerations to the Pittsburgh District will appear when it is recalled how narrowly we recently escaped having to vote upon a $35,000,000 bond issue, most of which was for roads and bridges, and for which few if any well considered plans or programs of construction and usefulness had been prepared. In the expenditure of such a large sum it is imperative that a system of highways be planned in advance and adapted to the needs of the region, as otherwise such expenditures may be largely wasted. This Society and all good citizens should oppose the spending of public funds for these purposes, unless it can be shown that intelligent foresight will guide such expenditures in accordance with the requirements of regional planning.

Parks and Boulevards. Another field in which the district form of organization has been found especially useful is in the planning, construction and maintenance of parks. One of the best examples is the Boston Metropolitan Park Commission, estab-

lished in 1893. It has broad administrative powers over parks and open spaces in a district of about 400 square miles, including 13 cities and 26 towns, with a total population of about 1,500,000, and has carried out some of the most important park and boulevard projects in the United States. Other examples of such park district commissions are the Bronx Parkway Commission of New York, the Metropolitan Park Commission of Providence, R. I., the Essex and Hudson Counties Park Commission in New Jersey, and the Metropolitan Park Commission of Cleveland.

The need of a similar organization in the Pittsburgh District is apparent. Schenley and Highland Parks are the playgrounds of the entire district, and the recent generous bequest of the late Henry C. Frick adds to the assets of the district another large park—the Frick Woods. Additional parks are needed in many parts of the metropolitan area, and all of them should be linked together by a system of parked boulevards, which would permit citizens of every part of the district to reach any part of the park system without disturbing that sense of restful recreation which it is the function of our parks to supply. The existing Bigelow and Beechwood Boulevards and the projected Monongahela Boulevard, with their splendid outlooks over the busy valleys in which our industries are located, and their connections to Schenley and Highland Parks, form the basis of a comprehensive boulevard system; but their value will be largely lost unless they are joined with a system extending throughout the metropolitan area and planned to meet regional rather than local requirements.

Water and Sewerage Systems. The advantages of regional water and sewerage systems are often particularly striking and serve excellently to illustrate the value of the regional plan. Water-supply problems depend for their solution more upon source of supply than upon any other consideration. The sources in any region, suitable for water-supply purposes, are limited in number and capacity, and a city may do lasting injury to a region by developing its supply without regard for the needs of its neighbors. This was recognized by a state department of health recently in our own practice, where approval on a joint project for two important cities was withheld until the state should have

had time to investigate thoroughly the water resources and the needs of all the population within the region.

Sewerage is strictly a drainage area problem, and unnecessary expense, as well as mutual damages of many kinds, results from attempts to solve it with respect to political boundaries alone. Moreover, the bodies of water into which sewage may be discharged, like the sources of water-supply, are limited in number and oxidation capacity, so that the problem of sewage disposal is also a regional, and not a local problem.

All of these advantages have been frequently recognized in the handling of water and sewerage problems. State departments of health have established supervision of water-supplies and sewerage systems, so as to prevent communities from injuring one another, and to maintain standards within state lines. And there are many examples of joint action by neighboring municipalities for the solution of their common problems; as at London, where the Metropolitan Water System supplies 2 cities, 27 metropolitan boroughs, 1 county borough, 7 non-county boroughs, 46 urban districts, 12 rural districts, 53 poor-law unions and 300 parishes, including an area of 537 square miles in six counties; at New York, where sewerage and drainage plans have been made for an area of 700 square miles in New York and New Jersey, with a population of more than 6,000,000; at Winnipeg, Canada, where the Greater Winnipeg Water District supplies an area of 91.7 square miles and a population of 238,000, in seven distinct political subdivisions; and at Boston, where the Metropolitan Water and Sewerage Board is charged with the sewerage and drainage of 14 cities and 13 towns, covering an area of 210 square miles and with a population in excess of 1,000,000, and supplies water to 10 cities and 9 towns, with a total area of 174.8 square miles and a population of over 1,300,000.

One of the most recent attempts to give public works service to an entire region is the development of the territory across the international boundary river from Detroit in the Province of Ontario, in Canada. Here there has been planned a joint waterworks and sewer system for seven municipalities, the largest of which is Windsor. The total area is 20.6 square miles and the total

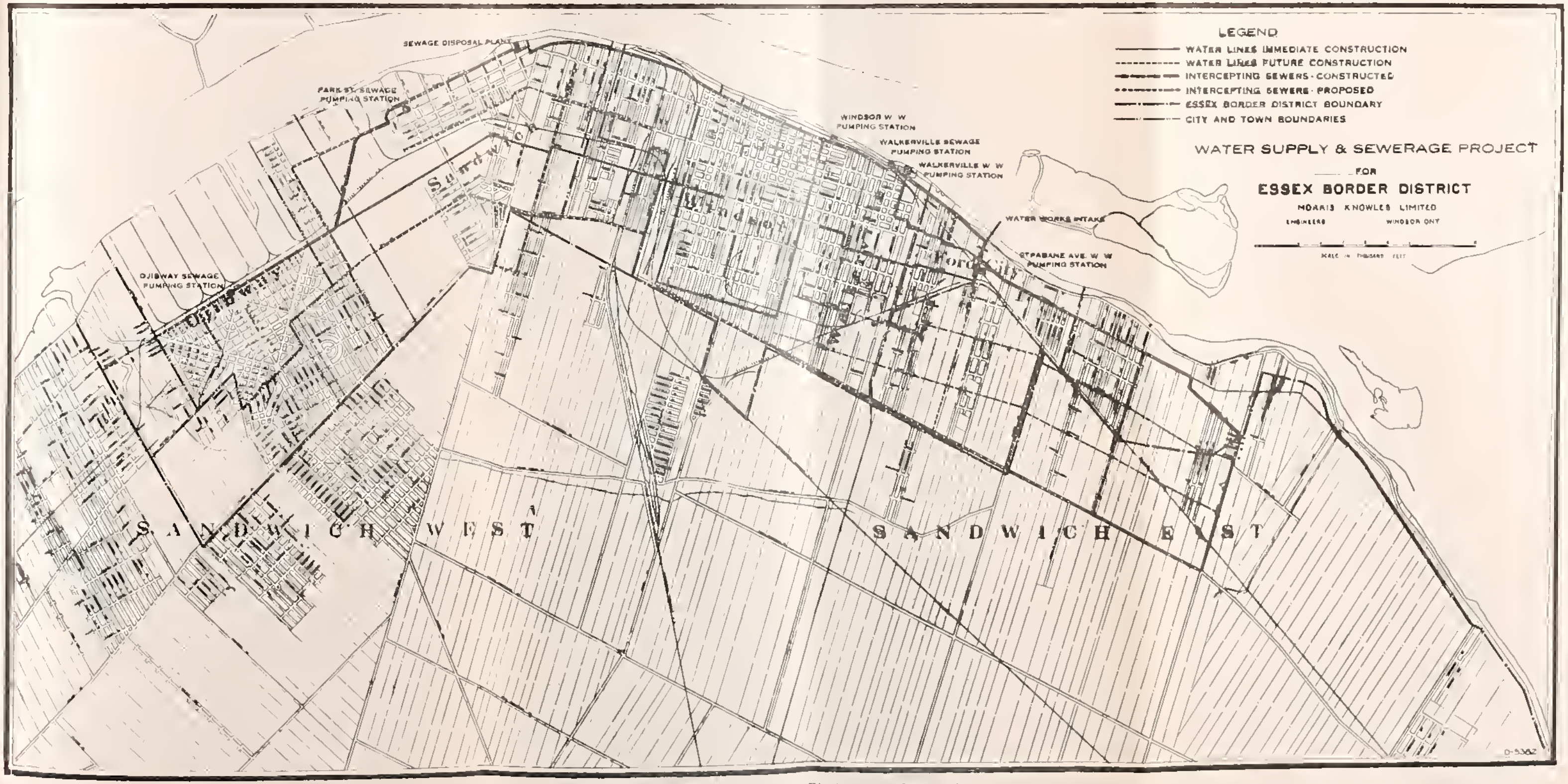

Fig. 5 Metropolitan Water and Sewer District, under Control of the Essex Border Utilities Commission, Ontario, Canada.

population is 58,500 and it is estimated that in 1950 the population will be 175,000.

The plan of the region with the source of water-supply and the main trunk lines for water and sewers is shown in Fig. 5 (insert).

Most of the efforts hitherto, however, have been gradual outgrowths compelled by the necessity of correcting the results of uncontrolled development. Regional planning proposes the substitution of foresight for hindsight, the study of water and sewerage problems for whole regions, with consideration of all the other related regional problems, and the adoption in advance of regional plans for water-supply and sewage disposal, in accordance with which development may be carried out.

As has been pointed out, there are numerous separate water-works systems and distinct sewerage systems in Allegheny County. A moment's reflection will show the close relation of many of these. For example, the City of Pittsburgh has a 60-inch steel main carrying filtered water to the North Side reservoir and passing through the boroughs of Aspinwall, Sharpsburg, Etna and Millvale. Each of these boroughs has a small water-works plant of its own, no one of which even approaches in adequacy, quality, efficiency or economy of operation the city supply, and many of which are now under orders from the State Department of Health to improve their supplies. Similarly, when a study was made for intercepting sewers and sewage disposal in the Saw Mill Run and Nine Mile Run drainage areas a few years ago, it was found that the only practicable method of handling the situation was by taking the sewage of several communities into the same sewers with that of the city. At some future date it may be necessary to collect all the sewage from the Greater City at some single point down stream, at which at least some minimum of treatment will be provided. This problem, involving the expenditure of millions of dollars, can be solved only by applying the principles of regional planning and developing a method of organization which will make the co-operation of all parts of the region available.

Stream Regulation. Another problem, for which satisfactory local solutions are obviously impossible and drainage area

solutions absolutely indispensable, is that of stream regulation and water conservation. Navigation requires a uniformly sufficient depth of water throughout the navigable length of the stream. Local flood protection works may actually increase flood heights above or below them. The interdependence of the water and sewerage problems of communities within a region has already been pointed out; while the best utilization of water-power requires that its development and distribution be based on regional, and not on local, considerations.

Moreover, it is of great importance that stream regulation be based upon the consideration of all of these uses of water, and not of one of them alone. A diversion for water-power purposes may destroy an important future source of water-supply. Certain types of flood protection works may prevent the utilization of a stream for navigation. Reservoirs may often be utilized for a combination of purposes. And the regional plan will consider stream regulation from the point of view of securing from the water resources of the region, at the lowest cost, the combination of uses which will contribute most to the welfare of the population, and to the solution of their other regional problems.

As in the case of water and sewerage, the advantages of stream regulation by drainage areas have been so long recognized that numerous examples can be found of the organization of districts for the development of regional stream regulation plans.

Typical of these are the co-operative organizations—for the drainage of swamp lands, the construction of levees and the prevention of floods—which are found in Canada and the United States and in other countries. The levee districts of the Mississippi Valley have united counties and states in the effort to protect property against the inundations of that great stream. Irrigation and drainage districts, created by the governments of the Dominion of Canada, and the United States, and by the water users' associations in the arid west, unite groups of owners of adjoining property to secure efficient and equitable control of their joint water-supplies.

A number of conservancy or flood prevention districts have been organized in the State of Ohio, the most important of which is the Miami Conservancy District, covering about 4200 square miles.

with a total population of about 1,000,000 people. This district was organized after the disastrous floods of 1913 to protect the city of Dayton and other cities in the valley of the Miami River from similar catastrophes in the future. Plans were prepared for the construction of a number of detention basins for flood prevention purposes. One of these basins has now been completed and all will shortly be dedicated to the service of the district.

Numerous similar projects will probably be undertaken in Ohio; and New York, Indiana, and Wisconsin have somewhat similar legislation. Pennsylvania has long been confronted with the flood and stream regulation problem, but as she has had abundant resources of coal, oil, and gas, the value of the use and control of water has not been appreciated heretofore. Within the last few years, however, a lively interest in these matters has developed in Pennsylvania, and it is hoped that legislation may be adopted before many years which will permit organization of districts, control of floods, increase of low water flow, and the development of power.

The thorough study of the flood situation in Pittsburgh which was made some ten years ago by the Pittsburgh Flood Commission, established clearly at that time that the problem was not a local one at all, but one in which great stretches of the rivers were involved and which would necessitate the construction of public works far beyond the city or county limits. Whenever suitable legislation is secured, one of the results which will be forthcoming will no doubt be the organization of a district to construct the 17 storage reservoirs recommended by the Commission.

It is to be hoped that this consummation may be attained before another great flood like that of 1907 is experienced, or before a still greater one arrives. For an estimate made in 1913, regarding what would have resulted if the center of the great storm of that year, instead of its outer edge, had been over the Allegheny and Monongahela watersheds, indicated a possible flood of 10 feet higher than the 1907 stage, high enough to put the Brilliant and Aspinwall pumping stations out of commission and to put the water up to Smithfield Street.

Light and Power. The type and location of regional sources

of light and power will depend largely upon the characteristics of the region with respect to availability and location of coal, natural gas, and hydro-electric power. But the economic advantages of power generation in large central stations need no demonstration in these days of efficient, large capacity generators and of high tension transmission. Enlightened self-interest has long recognized this, and the results may be seen in the unification of the gas supply systems in the neighborhood of every field of natural gas, and in the huge electric central stations and the network of electric supply and distribution lines which characterize every one of our large urban districts.

Regional planning proposes only to substitute for enlightened self-interest the broader consideration of all of the problems of the region, and realize these economies in the manner which will fit in best with the requirements of industry, transportation, water utilization, conservation of natural resources, and general welfare.

One of the great advantages of considering this problem from the regional point of view will unquestionably be the growth of the supply of light and power to rural districts and farms. Such a contribution to the comfort of farm life may go far toward counteracting the drift of rural population to the city, which in late years has so greatly threatened the maintenance of agricultural production and the abundance of food with which we have hitherto been blessed.

A most suggestive proposal relative to regional planning for power supply is found in the projected study of a comprehensive power system for the entire North Atlantic coast, from Washington to Boston, for which an appropriation has been granted by Congress. The plan to be studied, comprehends the interconnection of the power systems of the entire area; the joint utilization of existing central stations; the pouring into a "river of power," of current from the falls of the Potomac, Niagara, and the New England rivers; and the construction of giant generating stations at the mines and the coal fields of West Virginia and eastern Pennsylvania. See Fig. 6.

It is possible that the study may show considerable reduction in the cost of power throughout this region, as is claimed by its

Fig. 6. Approximate Super-Power Zone along Atlantic Coast.

sponsors. But whether it does or not, it will serve as a striking illustration of the broad lines upon which the regional solution of such a problem may proceed.

In the Pittsburgh District, private initiative has already developed comprehensive systems of gas and electric lights for the supply of light, heat, and power, and it may be hoped that, under the regulation of the Public Service Commission, our regional problems in these fields will be satisfactorily solved; for we still have our great regional problems, the natural gas situation constituting an excellent example. With the natural gas supply from the West Virginia field declining in quantity and increasing in cost, the industries and people of cities in Ohio, West Virginia and Pennsylvania are competing for the available supply. Clearly the greatest good from this available supply can be obtained only by intelligently rationing the various communities and the various uses involved, and the interest of all concerned requires that the question be approached from the point of view of regional planning.

In the electric power field, we find two important companies

sharing the burden of supplying the district, and it happens that each one is spending a number of millions of dollars at the present time on new power-plants. Even now there are five interconnecting points which make possible the interchange of facilities. The full efficiency and reliability of the regional system, however, will never be fully developed until the resources of all of the important stations are united. The future still holds important problems in regional planning, in the consideration of those combined power sources in connection with the needs of our electrified railroads; with the hydroelectric possibilities of Western Pennsylvania; and with the power net work of the whole northeastern portion of the United States.

Zoning and Districting. A basic part of city and regional planning, one which bears a relation both of cause and effect to each of its other problems, is zoning and districting—the classification of land and the determination in advance of the uses to which it is to be put. Question may be raised as to whether we are yet far enough advanced in wisdom and vision to district whole states and counties, separating agricultural and mining land from that to be reserved for the various uses of urban life; but there can be no doubt as to the desirability of extending the zoning and districting of large cities to the entire metropolitan areas of which they are the centers.

To take an example—the City Planning Commission of Pittsburgh is working on a zoning ordinance and has completed a tentative draft of the sections relating to use districts. As drafted, these sections provide for heavy and light industrial districts and various classes of residential districts. But even in the heavy industrial districts, certain "nuisance industries" causing objectionable odors, etc., are barred, and no provision is made within the city for any unrestricted area within which such industries will be permitted. Now a garbage rendering plant, for example, is a necessity in a large community like Pittsburgh, and it would be just as objectionable to the residents of our city if it were located just across the city line from a residential section as if it were in a city. Common-sense would dictate that all such essential nuisance industries should be grouped together and that the entire

region or district should join in setting aside an area for this purpose.

Smoke Prevention. One of the best examples of the problems calling for regional control is the smoke problem, as "the wind bloweth where it listeth," and smoke follows the wind. Pittsburgh had made great progress, prior to 1917, in the reduction of smoke, and it is to be expected that her leadership in that field will soon be re-established. But a large part of the benefit from Pittsburgh efforts inures to the neighboring boroughs into which Pittsburgh smoke is blown, and Pittsburgh will never be really smokeless as long as Homestead, McKeesport, McKees Rocks and other industrial cities and boroughs continue to make smoke to collect and settle down over the lower end of the Allegheny and Monongahela Valleys. Third-class cities and boroughs now have power to regulate smoke (though such powers are somewhat more restricted than in Pittsburgh). Much more rapid progress, however, might be expected if some form of metropolitan control would be devised, than if we must wait for separate action by the 72 municipalities.

Health Protection. Smoke regulation exemplifies the manner in which the advantages of regional planning of public works apply to the administration of those public services which are based upon the police power of the state. It has already been pointed out how readily a disease in one portion of a metropolitan area may spread, like smoke, over the entire area. So, too, the protection of health in any portion of the community can never be assured except by a uniformly efficient service over the entire district. Much could therefore be accomplished by means of a regional organization. In these services, the economy of co-operation is especially apparent. The City of Pittsburgh maintains many health services which are almost or entirely lacking in many parts of the district, including an isolation hospital, the tuberculosis hospital, systematic food inspection, child welfare, etc., the benefits of which could be extended to the entire district at little or no greater cost to the boroughs than the cost of their present part time, partial service.

Examples are not lacking of joint health service, one of the

most interesting of which was the co-operative health service, including milk inspection, plumbing inspection, laboratory service and all sanitary inspections, which was established under private management several years ago, for 11 small suburbs of the city of Boston. Although this was privately done for the local boards of health under contract, and without legislative enactment or any form of centralized political organization, nevertheless, on account of the public character of the experiment, and the public spirit of its supporters, it seems preferable to refer to it here, rather than as an example of "private enterprise."

Another example of the same sort has been worked out in the joint health service of three municipalities of La Salle, Oglesby, and Peru, Ill., having a total population of almost 28,000.

Police Protection. A certain amount of metropolitan policing is done in many cases where district commissions have been established for the maintenance of parks and other public works. Thus the Boston Metropolitan Park Commission maintains in the parks and reservations under its jurisdiction a police force consisting of 4 lieutenants, 12 sergeants and 135 patrolmen.

The important example of this application of the metropolitan district idea, however, is the territory under the jurisdiction of the Metropolitan Police Commissioners of London, including 693 square miles in the counties of London, Middlesex, Surrey, Essex, and Herefordshire, with a population of more than 8,000,000.

METHODS OF ORGANIZATION

Organization for carrying out the works of a regional plan is not solely an engineering problem. Existing political organizations must, of course, be the basis of it, and intricate legal and organization problems must be solved to build up the group of related organizations (for each problem may require separate organization) required to secure the results desired. But the selection of desirable types of organization is so closely tied up with the planning and use of the public works involved in a regional plan, that no consideration of its engineering problems would be complete without reference to it.

The type of organization depends in each case, not only upon

the existing political organization and upon the area and density of population of the region, but also upon the particular purpose, or combination of purposes, to be accomplished. Dependent upon these factors, examples of community co-operation can be found, varying through a wide range with respect to functions involved, degree of centralization of control, and methods of financing and apportioning cost. Most of the important cases, however, can be classified under one or the other of seven headings, as follows:

1. Extension of municipal limits, and consolidation or annexation.
2. Extension of municipal jurisdiction.
3. Contracts between municipalities.
4. County administration.
5. Private enterprise.
6. Borough plan.
7. District organization.

Annexation. The oldest of these methods and the one that has been resorted to in the growth of the region around practically every city is annexation—actual incorporation of adjacent territory into the city, and complete centralization of authority with respect to public works, public safety, legislation, taxation and all other municipal functions. This may be brought about by mutual agreement between the city and the annexed suburbs; or under some forms of legislation by a majority of all the voters in the territory affected, regardless of the wishes of the voters of the suburbs to be annexed.

Now what are some of the advantages and disadvantages of annexation? One likes to be considered, as Paul said, "a citizen of no mean city." There is, no doubt, some advantage in advertising value to business houses, banks, commercial institutions—even, perhaps, to the common citizen—in being able to refer to the city as larger than some competing neighbor. The large city, also, is better able to attract new industries, and to finance larger and more expensive public improvements. There is thus, perhaps, some real justification for the pride that is frequently taken in the figures published in the census reports. Furthermore, it is true in some instances that the territory lying adjacent to a city

is completely continuous with it in development—so homogeneous with it, in population and interests, that consolidation may be the best possible solution of the problem.

Size, however, does not always spell economy and efficiency. With the growth of the city, the old "town meeting" for expressing the desires of the citizens becomes impossible. It is difficult for the voters to keep in touch with the actions of their elected representatives. The problems of municipal government become increasingly complex and difficult, leading too often to misgovernment and dishonesty. A further disadvantage of annexation is the loss of local civic spirit, which is difficult to keep alive in the large modern city. For all of these reasons, annexation is not always looked upon with favor; particularly where the boundaries between adjoining communities are still distinct, where populations are not homogeneous, and where local interests, at some points, conflict. Under such circumstances, there are additional disadvantages in consolidation, for, if a majority vote of the citizens of the territory to be annexed is to be secured, it is often necessary to make undesirable concessions to them. And, if the territory is taken in against the wishes of a majority of its citizens, an antagonistic spirit is engendered that may take many years to eliminate.

All of these considerations apply to the Pittsburgh District. The past political history of Pittsburgh has not always been such as to engender confidence on the part of the neighboring municipalities, and, while conditions have improved enormously under the small council, there are still things to criticize, and there has not yet been sufficient time to live down the past.

Furthermore, the growth of the "home rule" idea, and of the application of the principle of self determination to small municipalities as well as to small states, has been such that few would have the temerity to-day to propose forcible annexation. Our Chamber of Commerce, our Civic Club, and the League of Boroughs, have gone on record as opposed to such a step, and all fair-minded citizens will agree that it is wholly undesirable.

Voluntary annexation may come about gradually over a long period of time, as the city demonstrates its capacity for government, and as municipalities immediately adjoining come to rec-

ognize more clearly their community of interest. But little can be expected from this method of organization toward the solution of our regional planning problems in the immediate future.

Extension of Municipal Jurisdiction. The recognition of this community of interest between city and suburbs, and of the futility of permitting the efforts of the city to be negatived by conditions just outside its limits has in some instances led to legislative extension of the city's jurisdiction, in certain respects, over areas lying outside its boundaries. This has been done most commonly in connection with town planning and approval of lot plans, but has been suggested for other municipal functions. In Pennsylvania, such control may extend to a distance of three miles beyond the city boundaries. In Virginia, such limit is 20 miles for cities of 50,000 and over.

This plan is applicable, however, only in cases where a large city is surrounded by small suburbs. Even in such cases, however, the control of the large unit is apt to be resented and opposed by suburban communities, and it would never be tolerated by a neighboring municipality approaching the larger city in population and importance.

Obviously, but little can be accomplished in the Pittsburgh District by this method of control.

Contracts between Municipalities. A third method of extending a single public service beyond the limits of a single municipality is by voluntary agreement evidenced by contracts. Thus a city may agree to supply water, dispose of sewage, or furnish other municipal services to an adjoining community for an agreed fee. Such an arrangement is limited in scope to comparatively simple cases, where the relations between the two contracting parties are clearly defined.

This method would hardly be successful where a number of communities of nearly equal importance are involved; not only because the contractual relations become so complicated as to make difficult their definition in advance; but also because, in such case, the municipalities are seldom willing to leave the operating control of the service in question entirely in the hands of one of their number.

Examples of such contracts, in connection with the furnishing of water, are of course to be found in Pittsburgh, but with the frequent changes of administration that characterize our municipalities, and the other difficulties that have been pointed out, we would be rash indeed to expect that any substantial portion of our regional planning problems can be solved on this basis.

County Administration. The county form of government has often been suggested as a means of carrying out some portions of a regional plan. The London County Council, which has charge of many of the municipal functions of the London Metropolitan District, is frequently cited as an example of its success. The illustrations of Philadelphia and Cook Counties for Philadelphia and Chicago, respectively, are also sometimes referred to. It must be remembered, however, that the saturation of population is quite complete throughout the areas referred to, and that these counties are practically coterminous in fact, as well as in political organization, with the cities in question. Ordinarily, conditions are entirely different and the wide variations in the degree of development of portions of the county, ranging from congested city property to farm lands, precludes the successful application of the county form of organization. Furthermore, county governments are particularly concerned with the administration of judicial functions; and they are neither efficient enough in organization nor sufficiently representative in personnel, to adminster the complicated municipal services of which we are speaking.

These general remarks are perhaps particularly applicable to counties in Pennsylvania, where the principle of minority representation, originally intended to elevate the conduct of the office of county commissioner, has resulted in the practical destruction of the function of the minority party and in a system of bi-partisan control which often blocks the effective working of democratic government. Our experiences with the construction and repair of roads and bridges in some of our counties have not always been such as would recommend to us the further extension of such administrative jurisdiction.

Private Enterprise. A very good demonstration of the ad-

vantages of centralization of control for certain types of public service may be found in the extensive public utility systems which have grown up under private ownership in many communities; and the economies that appeal to intelligent self-interest are just as valid as arguments for community co-operation.

These developments of private enterprise suggest a fifth method of securing the results of collective action; and, indeed, where municipal co-operation is impossible, or where conditions are such that the development is not likely to secure the services of men of the highest grade of ability under public control, it may be the best method, provided the public interest is protected by carefully drawn franchises, and by a comprehensive system of public utility regulation.

Numerous examples of this form of organization of regional systems may be found in the Pittsburgh District, among which may be mentioned the railroad systems, the Pittsburgh Railways Company, the Duquesne Light Company and the West Penn Power Company, the Pennsylvania, South Pittsburgh, Ohio Valley, and Beaver Valley water companies, etc. In these cases, it is probable that private ownership will continue, and that the development of public regulation will more and more successfully control these systems in the interest of the entire region. But many of our regional problems involve works and services, payment for which cannot readily be made by rates collected from users; and it is unlikely that in these days private ownership will be extended into any other field, particularly where the problems are on so large a scale as to justify the employment by the public of men of the highest degree of technical skill and administrative ability.

Borough System. A method of organization that is frequently urged for the solution of metropolitan problems is a borough system of government, and New York is often quoted as an example of its success. New York, however, stands so far apart from other American cities with respect to its size and its problems, that it is difficult to draw analogies; particularly as the New York government is not a pure borough system. Evidences are now apparent that even the boasted New York borough system

may be abolished, as many organizations are now working toward a new charter which will not contain this segregated form of government, but have one central council or commission.

A better illustration, perhaps, is the federated government which was proposed a few years ago for the consolidation of Berkeley, Oakland, Alameda, and eight other California towns, together with Alameda County. Under this plan (which has not yet been adopted) there would have remained 11 different boroughs, each with a borough board of five members, elected by the citizens of the borough, and exercising the following functions:

1. Police ordinance power, with regard to borough control over liquor and other regulations.
2. Exclusive power of appropriation for the following purposes:
    a. Paving, cleaning, watering, lighting, and repairing streets, except main thoroughfares.
    b. Construction and maintenance of sewers, except main sewers.
    c. Parks and playgrounds owned by the boroughs prior to the federation.
    d. Police and fire departments within the borough.
    e. Incidental expenses of the borough board.

All powers not specifically conferred on the boroughs were to be reserved to the city-county government, and the boroughs were to be required to pay their proportionate shares of the joint expenses.

The general government was to consist of a council of 21 members, nominated and elected to represent the same number of districts (which did not necessarily coincide with borough lines). The people were also to elect a district attorney, a mayor and certain judges; while the executive head of the city was to be a city manager, elected by the council. A diagram illustrating the proposed organization is shown in Fig. 7.

Whatever may be the applicability of the borough plan to communities including a small number of contiguous municipalities, it can hardly be considered applicable to the Pittsburgh District—both because of the number of municipalities involved, and

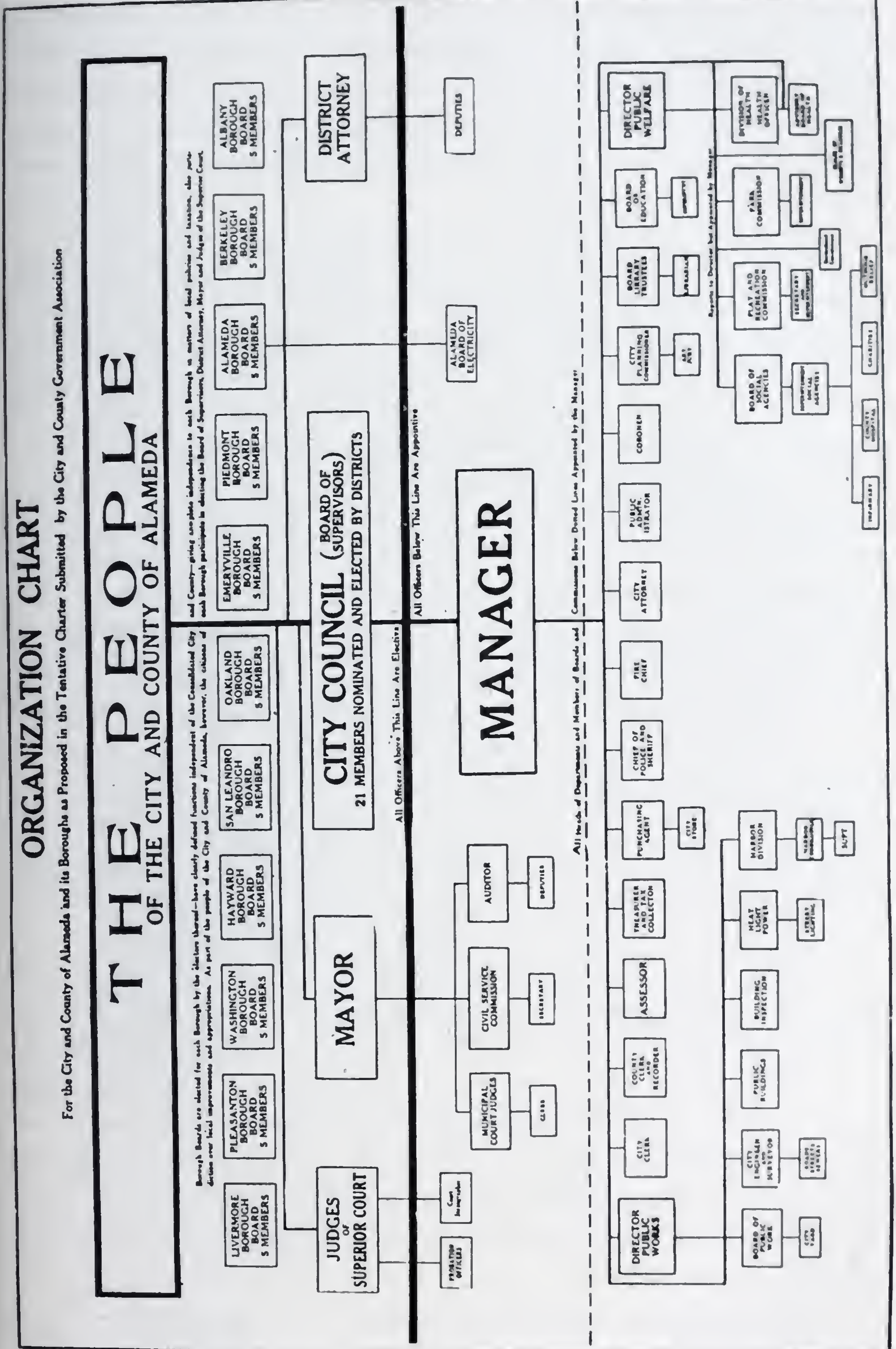

Fig. 7. Proposed Regional Organization Chart for a Group of California Cities and Towns.

because, as has been pointed out, the Pittsburgh District apparently is not yet ready for a consolidation of its legislative machinery. What must be found, in order to solve our regional planning problems, is a plan for co-operation in the administration of public works and services, without materially affecting the remaining functions of local government.

Metropolitan Districts. A great many of the defects of the methods of organization previously described may be avoided by the organization of neighborhood cities and adjoining suburban areas, for particular purposes, into metropolitan districts. Such districts, organized usually by particular legislation under the direction of representative commissions, leave the political functions of municipalities untouched, and thus preserve "home rule" and encourage local initiative and civic spirit. By confining their activities to specified public services, they tend to avoid the danger of political interference; by representative government, they protect the suburban municipalities from the domination of the larger cities; by including selected territory, the inequalities of county administration are avoided; and they can be adjusted to situations beyond the scope of any contract that might be drawn a priori. Thus all of the economy and efficiency of private enterprise is possible of attainment, with none of the objections to private ownership. In other words, the metropolitan district may achieve most of the advantages of the other types of organization described, while avoiding most of their undesirable features.

It must not be supposed that there are not pitfalls to be avoided in organizing a metropolitan district. The difficulty of securing complete representation, sometimes leads to opposition on grounds of "taxation without representation." The development of works ahead of immediate needs is apt to be criticized, but with wise planning only the general plan and a few permanent works need be designed for future conditions, the greater part of the construction being carried out from time to time as it is required.

The distribution and apportionment of the cost, and the determination of what part, if any, shall be borne by territory not yet developed but which will be brought into development by the

building of such works, are all difficult and have proved to be the rocks upon which many a good scheme has been wrecked. None of these dangers, however, is inherent in the method, and all of them may be avoided if local pride and self-interest can be eliminated and if a broad, public-spirited view of the situation will be taken by all.

Regarding these personal, as compared with physical, obstacles no better statement can be made than that of the late General H. M. Chittenden, in commenting upon the legal and political difficulties met in connection with the great regional undertaking of the Miami Conservancy District:

> "The greatest obstacles that the promoters of public work have overcome are not those of nature but of man. Nature is sometimes a stubborn adversary, but she always acts in the open, without subterfuge or indirection. But human ignorance, prejudice and self-interest are handicaps of a different character. Ignorance is least important, because it may yield to instruction. Prejudice—that is, prejudgment of a case and then sticking to it regardless of facts—is immeasurably worse. But self-interest is the most insuperable obstacle of all. Public measures are judged by their effect on the private pocketbook, and the rarest phenomenon in the world is willingness to subordinate personal interest to the public welfare."

As may be judged from these remarks, the writers are of the opinion that the "metropolitan district idea" (this convenient name for which was coined by them some years ago) is applicable to the Pittsburgh District, and indeed, as will be pointed out later, it is along these lines that they believe the solution of our regional planning problems will eventually be sought. It is, however, true that important changes in the constitution and statute law of Pennsylvania are necessary before any progress can be made in this direction.

APPORTIONMENT OF COST

Like the problem of organization, apportionment of cost is in large degree a financial, legal, and political problem. But like the selection of organization types, it, also, is so closely bound up with the use of public works, that it is largely an engineering problem, too. In most cases the method used may be classified under one of four headings, or as a combination of two or more of these, as follows:

1. General taxation.
2. Special assessment.
3. Excess condemnation.
4. Rates based upon quantity of service used.

General Taxation. General taxation requires no definition. It would provide simply that the portion of the cost of work so paid would be disbursed out of the funds of the region, state or nation and assessed upon taxable property, real and personal, or upon incomes, even, by the proper authority, in the same manner as that in which all of the taxes are assessed. It would be applicable only to the portion of the cost of works chargeable to the general interest, and would be normally confined to the region benefited by the works.

In some states, however, as for example in Pennsylvania, the creation of special taxing districts is now understood to be prohibited by the constitution, so that this document must be amended before general taxation can be utilized, except to the extent that contributions to the cost of works can be secured from the municipal, county, state and national governments.

Special Assessment. The method of special assessment, although originally an English idea, has had its greatest development in the United States. On the continent of Europe, only Belgium and Germany have used this principle to any considerable extent. Its history in Great Britain, however, covers more than two centuries. The first law was passed in 1662, authorizing the widening of certain streets in Westminster; and after the London fire of 1666, a similar act was passed to provide for the rebuilding of the city. In New York, in 1676, the cost of digging wells on Broadway and Pearl Street was assessed, one-half to the city and one-half to the property holders nearest the wells. The comprehensive special assessment law enacted for New York in 1861, is said to have been the first in the United States.

The theory underlying special assessments is that the property on which they are imposed receives particular benefits, and that general taxation for such purely individual purposes is unjust. Any community, individual, or land that receives a particular advantage should pay for it in proportion to the benefit derived.

Also, there should be no assessment in case no benefits are derived, and, as has been held by some court decisions, "Burdens in excess of benefits . . . must be borne by general taxation." T. M. Cooley in his "Treatise on the Law of Taxation,"* states the rule as follows:

> "The only safe and practicable course, and the one which will do equal justice to all parties, is to consider what will be the influence of the proposed improvements on the market value of the property; what the property is now fairly worth in the market and what will be its value when the improvement is made. . . . There can be no justification for any proceeding which charges the land with an assessment greater than the benefits. It is a plain case of appropriating private property for public use without compensation."

In Pennsylvania, the use of special assessments has been materially limited by court decisions, restricting such assessments to certain kinds of improvements, and to property immediately abutting thereon; whereas, special benefits may frequently be conferred over a considerable area in addition to abutting property. Both constitutional and legislative changes are desirable in order that this useful, and reasonable, method of paying for public improvements may be properly employed.

Excess Condemnation. A special application of the principle underlying the theory of special assessments is excess condemnation, which has come into vogue within the last few years in a number of the states. It frequently happens that in carrying out a public improvement, the full benefit cannot be obtained from it, nor can the full contribution to the cost which such benefit would justify be obtained, unless more property than that actually needed for the improvement is taken and replanned for new uses in harmony with the improvement.

Several of the states have authorized municipalities, in such cases, to condemn such additional property in excess of the necessities of the project and upon completion of the improvement, to resell the excess at its increased value.

Such a provision is reasonable and just, in so far as it contributes to the carrying on of the project in such a manner as to accomplish the maximum possible benefit to the community. But

*Ed. 3, 1912. Chicago: Callaghan.

if it is adopted in Pennsylvania, the writers hope that it will be sufficiently restricted so as to bar its misuse for the purpose of municipal real estate speculation.

Rates. This method of apportioning cost is applicable especially to public utility services, such as steam and electric transportation, light and power systems, and joint water-supply and sewerage systems. The determination of reasonable rates, so as to apportion fairly the necessary gross revenue, is an intricate economic and engineering problem, and public supervision by a utility commission is required to make sure that they are maintained at a reasonable level.

Some instructive examples of combinations of methods of apportioning cost are found at Boston, and Passaic, N. J.; and at Winnipeg, and Vancouver, in Canada. These are described below.

Boston Methods. The most notable examples of metropolitan financing in the United States are those of the Boston Metropolitan District for sewerage and water-works. As originally proposed, the assessments for the construction of the trunk sewers and disposal and outfall works were to be determined by three commissioners appointed by the Supreme Judicial Court, allotments to be made each five years in advance. No basis was stipulated in the original act. In 1906 it was enacted that the assessment upon the various cities and towns should be based upon the respective taxable valuations of property, to meet the interest and sinking-fund requirements for the sewer loan; and upon the respective populations of the several cities and towns, for the purpose of meeting the maintenance and operation expenses. In case less than the whole area of any city or town uses the system, such apportionment is based upon the population of the areas using the system.

For the purpose of assessing the cost of the water-works, Boston, the largest unit in the district, formerly paid each year the same proportion of the total annual cost that its assessed valuation during the preceding year bore to the total valuation of all the cities and towns in the district, but any city or town which had not reached the capacity of its own system and was not using water from the Metropolitan supply was assessed on the basis of

only one-sixth of its valuation. After deducting Boston's payment, the remainder of the annual cost was to be apportioned to the other cities and towns, one-third in proportion to their respective valuations, and two-thirds in proportion to their respective populations. It is evident that such a method of apportionment of expense would not tend to restrain waste of water.

Extravagant use and waste of water, which indicated an early need of providing a new source of supply, led in 1904 to a new method of assessment. The proportion for Boston was enlarged, and those cities and towns which had not reached the capacity of their own works and were not using the "Metropolitan Water" were assessed on the basis of one-fifth of their total valuation. The remainder was apportioned, one-third in proportion to valuation, and two-thirds in proportion to use of water during the preceding year. In the year 1907, because of the apprehension of the farmers in those portions of the state from which new supplies have been drawn, an act was passed, compelling those cities and towns which derived any portion of their water-supplies from without their own limits to install meters at the rate of 5 per cent. per year until all services should be metered.

Under each of these methods of assessment, a large burden was placed upon the city of Boston, which had the greater density both of population and valuation. One reason for this, which may be worth remembering in the formation of similar districts, was that the Metropolitan Water Board, upon beginning its work, took over all the lands, reservoirs, pumping stations and other water-supply works and property of the city of Boston, and paid for these a large sum of money.

Passaic Method. The method of assessment for the building of the trunk sewers and outfall works for the Passaic Valley was not fixed in the act, which was passed March 18, 1907; but an agreement, entered into between the Passaic Valley Sewerage Commission and the 3 cities and 12 towns and boroughs comprising the district, did fix, on March 15th, 1911, the apportionment of the expense and the method of making payments thereon.

The relative capacities required by the several municipalities were determined by the board of engineers. The cost of con-

struction was then apportioned between the several municipalities, somewhat in proportion to these relative capacities, allowing, however, about a 50 per cent. increase for the City of Newark, the largest place in the district. It was further agreed that the annual expense of maintenance and operation, and the administrative expenses of the commission, should be assessed upon the several municipalities in proportion to the amounts of sewage delivered by them into the main trunk, as determined by measuring devices to be maintained by the commission.

Winnipeg Assessment. The Winnipeg water act provides that one-half of the amount required for interest on first cost, sinking-fund payment, and cost of maintenance and operation, shall be borne by the land included within the water district, and which may be supplied from the works; and it is important to notice that it is land, exclusive of improvements. Certain lands held by the king, or for the use of the Dominion or Province, or by any municipality, or for public schools, hospitals, architectural, or horticultural societies, or burying grounds, are excluded. A special board is created for the fixing of these assessments. The other half of the total annual cost is to be borne by the sale of water to municipalities and to individual consumers.

Vancouver Payments. The Vancouver sewerage act provides for the assessment of 30 per cent. of the cost of the entire scheme upon all the municipalities of the district, in proportion to their respective land valuations. The remaining 70 per cent. of the cost of each project is to be assessed, in proportion to valuation, upon the lands within the drainage area affected. The annual cost of maintenance and operation is similarly assessed, in proportion to valuation, upon the lands located within the drainage districts affected.

LEGISLATION

It would be unbecoming of engineers to trespass so far upon the field of another profession as to attempt to present any complete review of the legal aspects of the questions we have been discussing. It may be worth while, however, to refer very briefly to a few of the leading constitutional and statutory conditions

with which any program of regional planning and organization must be squared.

Constitution. The present constitution of Pennsylvania, which it will be recalled came into effect January 1, 1874, provides for the creation of counties and the chartering of cities, and makes numerous references to boroughs, townships, and school districts. In one instance (Section 8 of Article IX), the enumeration of these five kinds of municipal corporations is followed by the words "or other municipality or incorporated district," and the opinion is held by some that this reference might be considered to authorize the general assembly to incorporate other districts. In general, however, such districts are considered to be prohibited under the decisions of the courts against the formation of special taxing districts, and under Section 20 of Article III of the constitution, which reads:

"The general assembly shall not delegate to any special commission private corporation or association, any power to make, supervise or interfere with any municipal improvement, money, property or effects, whether held in trust or otherwise, or to levy taxes or perform any municipal function whatever."

No reference is made in the present constitution to assessment of benefits or excess condemnation.

Constitutional Amendments. An act of June 4, 1919, authorized the appointment of a Commission on Constitutional Amendment and Revision, which, under the chairmanship of Attorney General William J. Schaffer, has made a thorough study of the constitution and has presented some very interesting suggestions for its revision. The final report of this Commission will be presented to the session of the legislature which meets in January, and the opportunity will be afforded to make a beginning toward those changes which are required to promote regional planning, either in the legislature or in a constitutional convention, if one should be held, as has been proposed. However, nothing will be accomplished unless a real demand for it is expressed by the people of the state, as some of our political leaders have already indicated that questions relating to revenue and appropriations, and party reorganization to conform to the new political situation

will be too engrossing to permit "tinkering" with the constitution, unless it is forced upon the attention of the legislators.

It is important, therefore, that public interest be sustained and expressed if the work of the Commission on Constitutional Amendment and Revision is to lead to anything; and one of the amendments proposed, which should receive the support of all interested in regional planning, is that relating to metropolitan districts. The preliminary draft published by the Commission under date of February 11, 1920, after providing that "The municipalities of this commonwealth are counties, townships, cities, boroughs, school districts and such other incorporated districts as the general assembly shall by law create," included the following section:

"The general assembly, in order to facilitate public works for the benefit of two or more municipalities, may provide for the creation of classes of incorporated districts which may extend over more than one municipality and may vest in such incorporated district one or more of the powers vested by law in the municipalities within their respective boundaries and additional powers, and may make any power so vested an exclusive power or a power concurrent with the municipalities wholly or partly within their respective boundaries. No such incorporated district shall be created or its boundaries extended or its powers increased except by the consent of at least a majority of such electors resident within the proposed boundaries of the incorporated district as shall vote on the question at an election which shall be held as may be provided by law. No incorporated district shall be created entirely within the boundaries of a city or borough."

This section, with certain changes to clarify and broaden its provisions, would serve excellently as a basis for suitable district legislation. Unfortunately, it is understood that even this has not been retained by the Commission in the final report which it will submit to the legislature, and while the printed final report is not yet available, it is understood that the following section has been substituted for the above:

"Subject to the provisions of general laws, any municipality may contract with any other municipalities for the acquisition by purchase, construction or otherwise, or for the maintenance, supervision, or operation of public works, utilities, improvements or other property in which they have or plan to have a joint interest. Such contracts may provide for the creation of boards, commissions or other agencies to effect any or all

of the purposes of such contracts; but no such board, commission or agency shall ever have power to levy taxes or to borrow money. All such contracts shall provide for the arbitration of any differences that may arise between the parties thereto."

This section adds little, if anything, to the powers with which the general assembly could endow municipalities under the present constitution, and provides only for contracts between municipalities which, as has been pointed out, are applicable only to a few simple regional problems, and offer no solution for the great majority of more complex cases. It is to be hoped, therefore, that something better may be adopted, if not on the recommendation of the Commission, through the pressure of intelligent public opinion on the legislature.

Other interesting recommendations in the preliminary draft by the Commission, which, with possible slight modification, ought to be adopted, related to special assessment and excess condemnation, as follows:

Section 18. The general assembly may authorize assessments against all properties whether abutting or not, which are particularly benefited by the construction, enlargement, laying out, widening, grading or other improvement of public highways, parks, buildings or other public works by the state or any municipality thereof.

Section 19. Whenever the public purpose for which land is taken can best be attained by acquiring more land than the commonwealth or the municipality proposes to retain, the commonwealth or the municipality, subject to such limitations as the general assembly may prescribe, may take all the land which in the judgment of the proper officials is needed for such purpose, and may thereafter dispose of portions thereof, subject to restrictions protective of the public interest.

Kind of Municipalities. While the constitution provides for the creation of certain kinds of municipalities, establishes limitations of municipal debt, and makes certain other provisions regarding municipal affairs, most of the details relating to the organization and government of municipalities are regulated by statute law. Under the constitution and these laws, there are 12 classes of municipal corporations in Pennsylvania—counties; cities of the first, second and third classes; boroughs; incorporated towns; townships of the first and second classes; and school districts of the first, second, third and fourth classes. (Poor districts for-

merly constituted an additional class, but since their functions and organizations are now consolidated with those of the counties and cities, no mention need be made of them.)

All of these classes of municipalities, except cities of the first class, and incorporated towns, are represented in the Pittsburgh Metropolitan District, each being organized and governed in accordance with the particular legislation relating to its class.

Allegheny County is administered by an elective board of three commissioners whose duties have to do principally with the courts, elections, care of the poor, and the construction and maintenance of court houses, jails, bridges and roads, and with the issue of bonds and levying of taxes for these purposes.

Pittsburgh has its council of nine members elected at large. and a mayor with veto powers, while its executive department consists, in addition to the mayor, of directors of public safety. public works, charities, public health and supplies, and of the city treasurer, the controller, the city solicitor, the assessors, and a sinking-fund commission.

McKeesport and Duquesne, cities of the third class, are each governed by a mayor and four councilmen, elected at large and each assigned to have charge of one of the five department of public affairs, accounts and finance, public safety, streets and public improvements, and public property. Thus the government of third-class cities approximates closely to the commission form of government. The progressive legislation relating to this class of cities also includes provision of the initiative and referendum.

The 70 boroughs in Allegheny County all fall under the control of the General Borough Act and its supplements. Accordingly they are governed by a mayor and seven or more councilmen elected at large in the smaller boroughs and by wards in the larger ones.

The 35 townships of the second class have three supervisors each, whose duties relate principally to the repair of roads and the levying of taxes for this purpose. Townships of the first class (of which there are 21 in Allegheny County) are somewhat more highly organized, having five or more commissioners and in addition to caring for the roads, exercise some supervision over public safety and public health.

The school districts, while corresponding geographically with other municipal sub-divisions, retain their separate organization, Pittsburgh having its board of education of 15 members, appointed by the judges of the common pleas court, while the remaining districts have elected boards of from five to nine directors, according to population.

It is this complicated overlapping mass of municipal corporations on which must be grafted whatever is to be developed in the way of organization to make regional planning and comprehensive development possible.

A PROGRAM FOR PITTSBURGH

All of the considerations that have been outlined, it seems to the writers, must be taken into account if the result is to have any possible chance of success. The detail of the program to be followed will have to be an outgrowth of discussion and study by the intelligent citizenship of all the municipalities making up the Pittsburgh area, and it is to be hoped that the Engineers' Society of Western Pennsylvania will take the lead in developing this program.

At this time, however, it seems that it should be possible to draw some general conclusions, and to formulate some principles which may well direct the course of these discussions. In the writers' opinion, these conclusions and principles are as follows:

1. "Forcible annexation" is undesirable, and as voluntary consolidation is improbable in the near future, except in a few special cases, annexation offers no material promise for the general solution of our immediate problems of regional planning.

2. Voluntary consolidation, however, should be encouraged wherever sentiment is favorable to it, and at the same time the government of Pittsburgh should be continuously improved so as to lay the foundation for eventual voluntary consolidation of the entire district.

3. Nor do extensions of municipal jurisdiction, county administration, contracts between municipalities, or the borough plan appear attractive as a means of solving our regional planning problems.

4. Private enterprise under public regulation may be counted upon, for the time being, to carry out the development of such of our public

services as are now entrusted to it. But its field will probably never be materially extended and is more likely, at some future time, to be contracted.

5. The Metropolitan District idea is the logical foundation for the measures required by the present situation.

6. Amendment of the constitution should be favored, so as to permit special assessments, excess condemnation, and the organization of metropolitan districts.

7. Legislation should then be secured authorizing the organization of such districts to construct and operate joint public works, when approved by the court or competent state authority; and, when authorized by vote of the people in any municipality, to take over the construction and operation of related local public works, or the administration of any joint service relating to public health or safety, within the municipality.

8. Such districts should be governed by commissions, which may be either elective or appointive, and which may either operate as under the commission form of government, each commissioner directing a department; or else through a district manager.

9. The commission should be authorized to contract indebtedness, to levy assessments for special benefits, and to charge equitable rates for service, where applicable; and, in addition, it should be authorized to finance its remaining requirements, if any, either by levying taxes, or by equitable apportionment among the several municipalities.

10. Such a district should then be created in the Pittsburgh metropolitan area—first for the construction of some single system of joint public works (such as intercepting sewers, for example) with the expectation that, when it should be successfully established, additional functions should be confided to it.

11. The municipalities within the district should then be encouraged to entrust to the district the administration of other joint public services.

12. The ideal of a homogeneous consolidated city at some future date should be kept in view at all times, and each step should be directed by the effort to develop such efficiency in public service, and such genuine community spirit, that all of the municipalities involved may, at the earliest possible moment, be glad to join voluntarily in creating that Greater Pittsburgh to which we may confidently look forward.

DISCUSSION

Mr. W. C. Hawley, *Chairman*:* We have listened to a most interesting paper. It is now before you for discussion or any question you would like to ask.

Mr. J. W. Freeman:† I remember reading some years ago about the capital of the Commonwealth of Australia. That scheme was spoken of as being such a wonder. Do they provide for future expansion?

Mr. Morris Knowles: Yes indeed. That is very interesting. It is a community work in this respect, it is the proposed capital of the nation located away off in the mountains in virgin territory. The intention is to build an entirely new capital city, and all the future planning has to do with a city of that kind.

Mr. J. W. Freeman: Have they actually broken ground?

Mr. Morris Knowles: I understand they did, but very little was done during the war.

Mr. W. C. Hawley: I am glad Mr. Knowles thinks forcible annexation out of the question. I believe that question has been settled by the boroughs and townships for some time to come.

Mr. Lee Digby:§ During the past two years a project has been developed for a boulevard to connect all the boroughs as far out as Braddock. The plan is to construct this boulevard through the valley of Nine Mile Run, commonly known as Fern Hollow.

This beautiful ravine runs from Homewood Avenue to the Homestead bridge. It is about 2.75 miles long and completely separates Pittsburgh proper from Wilkinsburg, Swissvale, Hawkins, and Braddock, leaving only one traffic route for automobiles to cover this vast territory. This single route is Penn Avenue, or the Lincoln Highway, as it is now called. Forbes Street is open only to street-car traffic.

*Chief Engineer and General Superintendent, Pennsylvania Water Co., Wilkinsburg, Pa.
†Sales Engineer, Mathews Gravity Carrier Co., Pittsburgh.
§Wilkinsburg, Pa.

Just think, in the heart of this great city only one street in three miles to reach five populous boroughs, representing about 200,000 people. Considering that this one street feeds the Lincoln Highway through to Philadelphia, you have some idea of the importance of this new project.

Now let us see what can be attained by the new boulevard. We start from East Liberty out Penn Avenue, to Beechwood Boulevard, cross Fifth Avenue to Reynolds Street, to Homewood Avenue, cross Homewood bridge to the boulevard, down Fern Hollow to Forward Avenue; from Forward Avenue over the hill through Schenley Park, connecting with all cross streets on Squirrel Hill; under the Pennsylvania Railroad to East Swissvale and Edgewood; through East Swissvale, connecting Hawkins and Braddock; through Bessemer to East Pittsburgh. From Forward Avenue, following an easy grade, we connect with West Edgewood; thence through West Wilkinsburg back to Penn Avenue, with crossings under the Pennsylvania Railroad at Edgewood station and at Rebecca Street, and South Avenue, Wilkinsburg. Back to the new boulevard, we follow down until we come to the graded street—Commercial Avenue—leading up to the isolated portion of the Fourteenth ward, to Colfax school-house and a great stretch of level land to Swissvale. (When this connection is made it will almost double the property value of this great stretch of country.) Now we continue down the new boulevard to the Homestead bridge, which leads to the vast steel district of Homestead and Duquesne, and on up the river without any interruption. This also connects with the Boulevard of the Allies running from the Point, in Pittsburgh, out Second Avenue to Hazelwood, thence to Rankin, passing Nine-Mile Run and connecting with the new boulevard under the Baltimore and Ohio tracks.

Now let us see what we have accomplished. First, we have connected East Pittsburgh, Bessemer, Braddock, Hawkins, Swissvale, Edgewood, and Wilkinsburg, with an average of about five per cent. grade streets. The boulevard itself will be about a three per cent. grade from Homewood Avenue to the Homestead bridge—directly connecting five boroughs with Homestead by a 15-minute ride by automobile.

This ravine, Nine Mile Run, is to-day one of the most beautiful, natural, deeply wooded, sunken parks in this country; and, when properly cared for, a more beautiful park could not be desired. This new boulevard passes through virgin forests and unimproved property, no part of which could claim damages. There would be very little cost for grading or filling, while all properties adjoining this new boulevard would be more than doubled in value. There is no place in the city of Pittsburgh where so great returns can be gained for city and boroughs with as little cost.

Last, and most important of all, is the fact that when completed this park, three miles in length, can be reached by no less than 250,000 people within easy walking distance of their homes, from Frankstown Avenue to Homestead. This is the natural park for the people of Pittsburgh from Point Breeze to Wilkinsburg; also for Edgewood, Swissvale, Rankin, and Braddock boroughs.

All of our parks should be made the great outdoor schoolrooms for the coming generations. There the children who in the future will maintain the higher ideals for America, should be taught to love the beauties of nature, and by easy stages learn to love and revere the Architect of these beauties, the grandeur in the woodland, the flowers, the ferns, and the living creatures that inhabit these regions.

On account of the enormous demand for building material and the high cost of wood, our forests are being relentlessly destroyed, and in a short time this country will be like parts of China, without trees. The only hope for restoration of the country and forest life, lies in educating the children to love this grand work; therefore this park should be used to teach forestry, agriculture, horticulture, botany, and the care of wild animals and bird life in this boundless school-room under the dome of the blue sky and the sunlight of nature's Creator.

Along the low lands on the boulevard could be planted the stately elm and sycamore trees, while the banks of the streams could be lined with willows and poplars. The hillside could be covered with the beech, birch, and maple for shade, the tall pine,

hickory, walnut, and butternut to add dignity, and the mighty oak to lend strength to the landscape.

With the movement for teaching protection of birds, now carried on by the schools, this park could be made the great school-room for children to help bring back the common birds.

Fern Hollow could very easily be brought to its original beauty by the collecting and planting of all varieties of ferns that are native to the state of Pennsylvania—which could be done by the school children with very little cost, as work in botany under the guidance of teachers in that study. Thus these woodlands could be made the school-room for the study of Nature.

In connection with the boulevard there is the great sewer system to be considered. As there has been $200,000 alloted for this purpose in the city bond issue, to complete the Nine Mile Run sewer, this subject should be taken up by the county engineers and State Board of Health in co-operation with the city engineers, to make a fine disposal plant for the boroughs as well as the city. Now is the time to test the possibility of carrying out the state laws, passed some years ago, compelling municipalities to take care of the sewage, so as to protect the rivers from pollution. This law has never been enforced.

Here is an opportunity for the Engineers' Society of Western Pennsylvania to make a name worthy of this highly trained body of men, and give to posterity their combined efforts and knowledge, in the battle against pollution leading to moral and physical degradation.

When the sewer is being laid, a great portion of the foundation for the roadway could be prepared, thereby saving unnecessary cost.

If the Society would enter into this scheme with the same spirit as one of its members entered into it, in making the maps for this article, they would look back with a great deal of pleasure upon a volunteer work that would become a great playground for the growing children of Pittsburgh's toilers.

MR. E. C. STONE:* The speaker has said something about the electric power development in this district. The plans of the power

*Assistant to General Manager, Duquesne Light Co., Pittsburgh.

companies seem to confirm the speakers' statement that sometimes private capital is more enterprising than the community. The Duquesne Light Company contemplates an expenditure in the next five or ten years of over $100,000,000 for development of the electric power system. In 1910 there were about 50,000 to 60,000 kilowatts of central-station generator capacity for this district. To-day there are 160,000. With the new plant at Cheswick, to which Mr. Knowles referred, there will be 215,000 initially, and 200,000 or 300,000 more within a few years.

I think the keynote to the very rapid development of central-station power in the last few years has been the rising price and the increasing scarcity of fuel. You are all familiar with the natural-gas situation and the price of coal, so that any means of conserving these natural resources is important. Engineers have estimated that if all the power used in this district could be served from large central stations with maximum economy there would be a saving in the territory of something like 1,000,000 tons of coal per year, which is a very important item.

There is another thing to think about in connection with these regional planning schemes and the availability of power; and that is that, where the territory is covered by central-station units, power is available anywhere, and the limitations due to the location of the power-plant, such as water, fuel, etc., are removed and any manufacturing industry can be developed anywhere in the territory wherever the best manufacturing proposition can be found. With a supply of power available anywhere—as it is when created at a central plant—and distributed all over the territory, the individual development can be anywhere in the territory where conditions are most favorable for manufacturing rather than for generating power. It seems to me that this will be one of the greatest helps that we are going to have in the next few years in getting away from overcrowding in restricted areas.

The three points which it is desired to bring out are: first, the very rapid development of the central electric power system in this district; second, the effect of such development on the conservation of fuel; and third, its effect in relieving overcrowded conditions in the present congested manufacturing areas.

In connection with the different systems, there have been instances where power available in the Pittsburgh District has been used down in Canton, Ohio. That does not mean that we transmitted power there, but a serious plant break-down made it necessary for them to have power. They called on the American Gas & Electric Company, at Windsor; Windsor called on the West Penn Power Company, at Connellsville; and the West Penn called on the Duquesne Light Company, at Pittsburgh. Due to the fact that we have these interconnecting lines there is a great advantage in power supply.

Mr. Winters Haydock:* I am not a member but I would like to ask a question in regard to the proposed constitutional amendment. Most of us who have studied the matter agree that the amendment as now written and as it will probably be submitted by the Commission is quite unsatisfactory. It is superfluous. Can Mr. Knowles suggest a means by which the Commission can be made to see the thing in the proper light and modify this suggestion to be submitted to the legislature?

Mr. Morris Knowles: I have not been in close touch with the situation. I understand, however, that that which is proposed by the Commission is really of no effect and practically permits no more than that which can be done at the present time. As to what may be done, we are all citizens and our wives, sisters, and mothers are citizens. There is going to be another chance, because nothing can happen until the legislature passes upon it, and the Committee hearings occur first, and it will have to be passed perhaps twice, in the form of amendments; and then there is the vote of the people. Of course, the real chance is in committee hearings, and if people will go there and make themselves heard, and if engineering organizations will make themselves heard upon a subject which is so closely allied to technical science, it will be effective; because, after all, if we can not secure something of that sort we will fail to solve many of the problems that need to be solved in this district and Pittsburgh will not go ahead. Pittsburgh needs to have many of its problems solved to care for in-

*Chief Engineer, Citizens Committee on City Plan for Pittsburgh.

dustry and to take care of the people who live here. What can we do? We can do what other citizens can do.

Mr. Winters Haydock: Do you think there is any hope?

Mr. Morris Knowles: I am not informed, as I say. I have not attended the meetings of the Constitutional Committee. I was out of town. I understand, as far as the Committee itself is concerned, that the report as I last read it for that particular section will be presented to the legislature.

Mr. W. C. Hawley: Mr. Knowles seemed to convey the idea that the difficulty was with the boroughs on this question of annexation. As a resident of the Wilkinsburg district I think the shoe is on the other foot. If the "business" council of Pittsburgh could get down to business and eliminate politics, local and national, the boroughs would not stay out a great while. Under existing conditions, I believe it will be a long time before they will come in voluntarily.

Authors' Closure: It is gratifying to have the stimulation given by the discussion. The remarks by Mr. Stone indicate further possibilities in regional operation of power units and transmission lines.

Mr. Digby's suggestion for a boulevard through Fern Hollow is particularly interesting, and to the esthetic lover of nature it presents interesting possibilities, especially when the Frick Woods will have been developed. So, too, the advantage is apparent of reserving the boulevard strip, which at the same time will function as a right of way for a big drainage line and sewer for the tributary area. As an argument for bringing the adjacent territory into the city, however, it may not be applicable except for ease of transportation of the inhabitants, as the facilitating of political annexation does not seem to be inherent in the project.

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, December 2 at 4:15 P. M., President W. C. Hawley presiding, Messrs. Danforth, James, Snyder, Spellmire, Speller, Hunter, Hildner, Paul and the Secretary being present.

The Minutes of the last regular meeting held November 4 were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Crew, Joshua Arthur	Selkirk, W. Marshall
Fitzgerald, Thomas	Smith, Howard Wells
Knopf, J. R.	Sollie, Klaus

Tracy, Louis Downer

ASSOCIATE MEMBERS

Adams, Howard Clark	Lacy, Robert
Hesselink, Lawrence Rynhart	Kerr, William Given

Van Deventer, Frank M.

Applications were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Becker, Joseph	Lehman, Albert C.
Boothman, Dale M.	Lowe, Wilfrid D.
Erhard, J. M.	Monro, William L.
Heppenstall, C. W.	Patterson, W. J.
Lamm, Lee L.	Schiller, William B.
Lanahan, Frank J.	Sutherland, William Chester

Weir, E. T.

The following applications were received for transfer to higher grade of membership, and after discussion, the Secretary was requested to write these gentlemen advising that they had been transferred to the grades as stated:

MEMBERS

Moore, H. Lee
Rederer, B. S.
Weinberg, B. B.

ASSOCIATE MEMBER

Ritts, Arch V.

Request for reinstatement was received from Mr. William A. Cornelius, and the Board requested that a letter be written Mr. Cornelius, advising that his name had been placed on the Society Rolls.

Letters of resignation were received from the following gentlemen, which after discussion, were ordered accepted:

Landgraf, F. K.............................Joined June, 1913
Prack, A. E.....................................Joined June, 1918

Letter was also received from Mr. W. P. Rieseck, and the Secretary was requested to write him and endeavor to have him withdraw his resignation.

The Secretary reported the death of Mr. A. L. Dole, who joined the Society May, 1914, and died March, 1919.

The report of the Secretary showing the financial condition of the Society at the close of business October 31, having been previously audited by the Finance Committee, was approved.

COMMITTEE REPORTS

Mr. James, Chairman of the Entertainment Committee, reported verbally stating that no meetings of the Committee had been held during the past month, but that arrangements were under way for the Annual Dinner, the date of January 24, having been finally settled upon.

Inspection trip to the Macbeth-Evans Glass Company had to be cancelled due to alterations at the plant, which necessitated their shutting down on the date scheduled for the trip. However, it is hoped that this trip can be held shortly after the first of the year. No other trips have been planned for the immediate future, as it was felt that it would be better to wait until after the holidays.

Mr. Speller, Chairman of the Finance Committee, reported that during the month $1300 was transferred from the Reserve Fund to the General Fund as authorized by the Board of Direction.

The Finance Statement of October 31 shows a decrease in balance in the General Fund from $620.40 to $348.22, as shown in report for October.

There has been an increase in receipts for October and November, 1920, of approximately $1600.00 over the same period for 1919.

As stated last month, the printing costs show the largest item of increase. The Secretary is looking into possibility of getting lower bids on our printing from outside printers.

Response from members having delinquent dues has been fairly satisfactory as a result of letters sent out last month, but another appeal is being made to those whose dues are not paid up.

In the absence of Mr. Schatz, Chairman of the House Committee, the Secretary reported an evening attendance of 19 for the month of November.

Mr. Hunter, Chairman of the Membership Committee, reported that eight invitations were accepted of the thirty-five sent out to the executives, asking them to join the Society.

Letters are to be sent to all members of the four National Societies residing in Pittsburgh who are not now members of the Society, inviting them to join in accordance with a special ruling of the Board, allowing them to join without the payment of an entrance fee or the necessity of filling out an application blank.

Letters were written to three men sending in letters of resignations on account of leaving the Pittsburgh District, and their resignations were withdrawn.

Mr. Spellmire, Chairman of the Publication Committee, reported that papers had been provided for the regular meetings of the Society.

Also that a special meeting had been arranged for as of December 8, at which a full attendance was desired, for the consideration of important matters relating to the American Federation of Engineers and our relation to this body.

The Secretary reported that a committee from the Practicing Engineers had called at the office (consisting of Mr. B. P. Blum and Mr. F. G. Rose), stating that the matter of becoming members of the Society had been discussed at the last meeting of their organization, and while the majority were in favor of the move, some were in doubt as to the method of admitting members to their section, and the manner in which questions coming before the section for a vote should be taken care of in their present By-Laws. Only engineers engaged in an established engineering practice independent of ordinary salary or professional employment, are eligible for membership and while the Committee realized that the Section could not have direct control over the election of members, they desired to have this

incorporated in their By-Laws in such a way as to place a direct obligation on the part of the Board of Direction to see that only engineers of this class were admitted to membership in their Section.

They also wished to incorporate a new article covering the matter of a firm vote, as under the By-Laws of our Society each individual member has a vote rather than the firm. They requested the Secretary to draw up a tentative constitution and by-laws in accordance with the by-laws of one of our Sections and have it approved by the Board of Direction, after which it could be presented to their organization for their approval.

After discussion it was moved and carried that the Committee composed of Mr. John A. Hunter, Chairman, and Mr. H. D. James and Mr. George H. Danforth, who previously met with the committee from the Practicing Engineers, go over these By-Laws and approve them before they are finally submitted to the Practicing Engineers. The Secretary was requested to send copies of these By-Laws to each of the above mentioned gentlemen.

The Secretary presented a letter from Mr. E. I. Mitchell, Asst. Secretary of Engineering Council, requesting that our Society take action on the report of the sub-committee of Engineering Council on the Classification and compensation of Engineers.

After discussion, it was moved and carried that a copy of this report be distributed among members of the Board of Direction and that the matter be held over until the next meeting, thereby allowing time for members to read the report and take action at the next meeting.

The Secretary presented a letter from Mr. P. H. Conradson, Consulting Chemist of the Galena-Signal Company, Franklin, Pa., stating that the International Engineering Congress is to be held 1923 under the auspices of the Swedish Technology Society, asking whether an invitation to the Society to be represented at this Congress would be acceptable. After discussion, it was moved and carried that the Secretary write Mr. Conradson, stating that an invitation would be very acceptable, and if possible, the Society would have a representative at this Congress.

In accordance with the By-Laws, it was moved and carried that the Board finally approve the eligibility of nominees for officers for the ensuing year as published in the November announcement.

The Secretary presented the following petition signed by fourteen corporate members of the Society, requesting the Board to approve the formation of a Steel Works Section.

After discussion, it was moved and carried, that the application be approved and the Secretary instructed to bring the matter before the General Society at the next regular meeting in accordance with the By-Laws.

November 8, 1920.

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The undersigned members of the Engineers' Society of Western Pennsylvania believing that the objects of this Society can be materially furthered by the formation of a Steel Works Section of the Society, do hereby make formal application for the formation of such a section as provided in the By-Laws of the Society.

Our Society exists in the heart of the greatest steel works section of the country and it is believed that the Society can do much more towards filling its proper position in this community by including a Steel Works Section among its activities.

We sincerely trust that the formation of this Section will meet with your approval and that you will so report at the next meeting of the Society.

(Signed) W. E. Snyder
F. N. Speller
John A. Hunter
C. W. Bennett
F. E. Leahy
W. P. Chandler, Jr.
Thos. P. Davies
A. N. Diehl
Alex. L. Hoerr
H. N. Pendleton
A. B. Holmes
G. H. Neilson.

The meeting adjourned at 5:40 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The Regular Bi-Monthly Meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, December 7 at 8:15 P. M., Chairman George T. Ladd presiding, 84 members and visitors being present.

The Minutes of the last meeting held October 5 were read and approved.

No further business coming before the Section, the paper of the evening on "The Underfeed Stoker—Its History and Application," was presented by Mr. Edward Rahm, Jr., Sales Engineer, The Uunder Feed Stoker Company of America, Pittsburgh, Pa.

Written discussion was received from H. N. Scofield, Gen. Sales Mgr., American Engineering Co., Philadelphia, Pa.

The ensuing discussion was participated in by: Joseph Breslove, Consulting Engineer, Pittsburgh, Pa.; F. F. Espenschied, Power Engr., W. E. Moore & Co., Pittsburgh; J. P. Horne, Sales Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.; T. A. Peebles, Chf. Engr., The Hagan Corporation, Pittsburgh, and the author.

On motion the meeting adjourned at 10:25 P. M.

K. F. Treschow, *Secretary.*

SPECIAL MEETING

A Special Meeting of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Wednesday, December 8, at 8:15 P. M., President W. C. Hawley presiding, 23 members being present.

Mr. Hawley called the meeting to order, stating that the meeting had been called at the request of the Board of Direction to consider the question as to whether or not our Society should join the Federated American Engineering Societies and the manner in which the financial responsibility should be handled.

The Board felt that it should not take final action on this question before the matter had been put before the Society to give the members an opportunity to learn all details, after which a referendum should be taken.

In order that we become thoroughly familiar with all details in regard to the organization, the Board requested the Publication Committee to secure a member of the American Engineering Council to speak at the meeting and secured Mr. McClellan, a member of the Executive Board of this Council, who gave a detailed account of the aims and objects of the organization.

After a general discussion, the following resolution was adopted:

Resolved: That it is the sense of this meeting that the position of the American Federated Engineering Societies shows an opportunity for progress and that the Board of Direction of the Engineers' Society of Western Pennsylvania be requested to take such steps as seem wise to them to secure all possible information, including the cost and ways and means of meeting same, after which the results of this investigation be put before the Society for a referendum, before taking final action.

It was moved and carried that a vote of thanks be extended to Mr. McClellan for his courtesy in coming to Pittsburgh, and the very able manner in which he has given us the details of this new organization.

On motion the meeting adjourned at 10:00 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 391st Regular Meeting of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, December 14, at 8:20 P. M., President W. C. Hawley presiding, 92 members and visitors being present.

The Minutes of the last regular meeting held November 16 were read and approved.

The Board of Direction reported the election of seven applicants to the grade of Member and five to the grade of Associate Member; the receipt of thirteen applications to membership; transfer of three to the grade of Member, and one to Associate Member; reinstatement of one applicant to the grade of Member, and the receipt of two resignations.

There being no further business before the Society, the paper of the evening on "Steam vs. Electric Drive for Power House Auxiliaries," was presented by Mr. G. G. Bell, Engineer, West Penn Power Company, Pittsburgh, Pa.

The ensuing discussion was participated in by: H. C. Cronemeyer, Designer, Jones & Laughlin Steel Co.; H. M. Graham, Asst. Chf. Engr., The Elliott Co.; B. F. Groat, Cons. Engr., Pittsburgh; B. M. Herr, Dist. Sales Mgr., Edward Valve & Mfg. Co.; T. E. Keating, Gen. Engr., Westinghouse Elec. & Mfg. Co.; Walter B. Spellmire, Mgr., General Electric Co., and the author.

It was moved, seconded and carried unanimously that a vote of thanks be extended to Mr. Bell for his very excellent paper.

On motion the meeting adjourned at 10:35 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING

CIVIL SECTION

The Annual Meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, January 6th, at 8.17 P. M., Chairman J. H. Minton presiding, 73 members and visitors being present.

The Minutes of the last Annual Meeting were read and approved.

The Nominating Committee reported nominations of the following officers for the ensuing year.

L. F. W. Hildner..Chairman
Louis P. Blum..Vice Chairman

P. S. Whitmar
P. W. Price
C. M. Reppert ....Directors
J. Toner Barr
E. E. Lanpher

No further nominations being made, the Secretary was instructed to cast a unanimous ballot for the members named, who were thereupon declared elected.

There being no further business the meeting adjourned and the regular Bi-monthly Meeting was called to order by Mr. Minton, in the absence of the new chairman, L. F. W. Hildner.

The Minutes of the last Regular Meeting held November 11th, were read and approved.

There being no further business, the paper of the evening on "Construction Work by the Cement Gun Method" was presented by Mr. A. J. White, District Manager, Cement Gun Construction Company of Chicago.

The ensuing discussion was participated in by: A. P. Krepp, Mech. Engr., Universal Steel Co, Bridgeville, Pa.; A. E. Blake, Sales Engr., Surface Combustion Co.; E. V. Braden, Engr., Pittsburgh Chartiers & Youghiogheny Ry.; J. R. Cline, Practice Man, Universal-Portland Cement Co.; J. A. McEwen, Mgr., Pittsburgh Bridge & Iron Wks.; C. N. Haggart, Cons. Engr., Pittsburgh, Pa.; Willis Leriche, Dist. Mgr., Cement

Gun Co., Chicago, Ill.; J. P. Toler, Chf. Engr., Crescent Portland Cement Co., New Castle, Pa.; Paul S. Whitman, Engr., Riter-Conley Mfg. Co.; A. L. Hoerr, Chf. Engr., National Tube Co., McKeesport, Pa.; C. T. Day, Detailer, American Bridge Co.; Prof. H. R. Thayer, Associate Professor, Structural Design, Carnegie Institute of Technology; P. J. Freeman, Testing Engr., Pittsburgh Testing Laboratory, and the author.

On motion the meeting adjourned at 10:15 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, January 8th, at 4:20 P. M., President George H. Neilson presiding, Messrs. Hunter, Spellmire, Pittman, Hoerr, Snyder, Hawley, Frohrieb and the Secretary being present.

The Minutes of the last meeting held December 4th, 1919, and of the Special Meeting held December 16th, were read and approved.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board were elected to membership:

JUNIORS

Templin, Richard L. Thorn, Thomas H.

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Gordon, Harold L. Hepburn, Peter W.

ASSOCIATE

Brown, Robson D.

JUNIOR

Pontzer, Edward Andrew

Letters of resignation were received from the following gentlemen, which after discussion were ordered accepted:

Bixby, William H.	Joined	Sept.	1912
Banfield, H. F.	"	May	1910
Burd, F. J.	"	Mar.	1918
Gebhart, F. E.	"	June	1915
Gordon, A. F.	"	Oct.	1915
Kunkle, C. E.	"	Mar.	1912
Landes, C. G.	"	June	1910
Lynde, C. C.	"	Mar.	1916
Lyon, D. A.	"	Nov.	1912: March 1919
McIntyre, C. A.	"	Oct.	1915
Ottesen, F.	"	May	1908
Parsons, W. J.	"	Mar.	1917
Patterson, C. T.	"	Oct.	1919
Work, W. R.	"	June	1916

The Secretary reported the death of Mr. Joseph A. Shinn, who joined the Society March, 1903, and died May 15, 1919.

The report of the Secretary showing the financial condition of the Society at the close of business November 30th, 1919, having been regularly audited by the Finance Committee, was approved.

COMMITTEE REPORTS

Mr. Hawley, Chairman of the Entertainment Committee, reported verbally stating that the Committee had endeavored to hold one or two meetings during the month and arrangements were under way for the coming Banquet, which gave indications of having a large attendance, as reservations up to the present time showed a substantial increase over previous years.

Mr. Pittman, Chairman of the Finance Committee, reported verbally stating that the accounts of the Secretary had been audited to November 30th and found in good order.

Mr. Spellmire, Chairman of the Publication Committee, reported that papers had been provided for all meetings for the fiscal year.

On motion the meeting adjourned at 5:15 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING

The Fortieth Annual Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, January 20th, 1920, at 8:20 P. M., President George H. Neilson presiding, 41 members and visitors being present.

The Minutes of the last Annual Meeting held January 21st, 1919, were read and approved.

The Annual Report of the Board of Direction, which included the reports of the Standing and Special Committees, the Sections and the Treasurer, was read as follows:

REPORT OF THE BOARD OF DIRECTION

The Board of Direction of the Society held ten regular and two special meetings during the year, at which routine business of the Society was transacted.

During the year there were nine regular, two special and the Annual Meeting of the Society. Total attendance was 1391, the average being 116. The maximum attendance was 334 at the April meeting and the minimum 39 at the November meeting. The average number participating in the discussion of papers was five.

At the close of the year the membership of the Society was as follows:

Honorary Members	2
Members	1040
Associate Members	63
Associates	33
Juniors	105
Student Juniors	7
	1250
Dropped	17
Resignations	36
Removed by death	13
	66
Accessions	114

Respectfully submitted,

K. F. Treschow, *Secretary.*

REPORT OF HOUSE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The evening attendance in the Society Rooms for the past year was 487.

The *Electrical World* and *Power* magazines have been added to our library magazines and all subscriptions expiring at this time have been renewed.

Improvements in the present arrangement of the store room are under way and will be completed at the earliest possible moment.

Prices have been received from various cabinet manufacturers on two magazine racks, which are to be installed in the Library to replace the table now used and we hope to have this change completed within the next month or two.

The question of quarters has been taken up and discussed, and is also being given attention, owing to the fact that our lease expires March 31st, 1922, and we have taken steps to secure the same or better quarters in the same building. The main point in favor of making the change is to have the Society Rooms and Auditorium closer together, as we believe more members would visit the Society Rooms if this were done.

Respectfully submitted,

F. C. Schatz,
Chairman, House Committee.

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

During the year two meetings of the Committee were held, with an average attendance of six.

Papers read at the general meetings of the Society.... 10
Papers read at the meetings of the various Sections.... 13

Two special meetings were held, one for discussion of the subject of a National Department of Public Works and the other on the Bond Issue and Subway.

Of these, twenty papers have been published in the Proceedings of the Society or will appear in later issues.

The Secretary has been getting prices for our new printing contract, but the contract has not been let.

Respectfully submitted,

W. B. Spellmire,
Chairman, Publication Committee.

REPORT COMMITTEE ON ONE HUNDRED FOOT STANDARD

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your committee on the installation of 100 Foot Standard in the City-County Building report that designs are completed and substantial progress is being made.

Respectfully submitted,

LOUIS P. BLUM, *Chairman.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

On account of conditions during the year, it has been impossible to arrange for the usual number of inspection trips. The Committee tried to arrange for several trips but was only able to arrange for one. This was made to the plant of the Republic Iron & Steel Company, Youngstown, Ohio, on June 7th, the trip and entertainment being provided by the William B. Scaife & Sons Company. The attendance was 320.

Two Smokers were held, one on April 12th and one on May 17th, at the Fort Pitt Hotel. The attendance at the first was, for some unknown reason, much less than had been anticipated. The receipts were $171.00, and the expenses $291.25. The street car strike was in progress on May 17th, and as a consequence the attendance was only 48. The receipts were $72.00, and the expenses were $276.20.

On June 19th, we had our steamboat excursion with an attendance of 97. The receipts were $131.25 and the expenses $413.08.

On November 8th, at the Fort Pitt Hotel we had an entertainment and dance. The evening was most enjoyable, but again the attendance was small, only 101 being present. The receipts were $151.50, and the expenses $270.77.

Respectfully submitted,

W. C. HAWLEY,
Chairman, Entertainment Commitee.

MEMBERSHIP COMMITTEE REPORT

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

At the close of the year 1919, the membership of your Society was as follows:

Honorary Members	2
Members	1040
Associate Members	63
Associates	33
Juniors	105
Student Juniors	7
Total	1250
Dropped	17
Resigned	36
Died	13
	66
Accessions	114

Not a bad showing considering after the war conditions.

Respectfully submitted,
GEORGE H. BARBOUR,
Chairman, House Committee.

FINANCE COMMITTEE REPORT

Engineers' Society of Western Pennsylvania,
Pittsburgh, Pa.:

Dear Sirs:

The books of the Society have been audited by the Committee every month during the last year and found correct and in good order. An independent audit for the year ending July 1st, 1919, was made by Ernst & Ernst, expert accountants. Their report shows the records to be correct and in good order.

Close check has been kept during the past year on members becoming delinquent. Letters requesting settlements of delinquent accounts have been sent out at frequent intervals and the results have been found very satisfactory.

Cash assets were increased $475.00 during the year.

All entrance fees have been deposited in the permanent fund each month, and the fund is paid up to December 31st, 1919.

There was an increase of $1400 in total receipts for the year.

Respectfully submitted,

E. W. Pittman,
Chairman, Finance Committee.

TREASURER'S REPORT

Receipts		*Expenditures*	
Dues 1920	$ 7.50	Administration	$ 4,083.00
Dues 1919	10,272.00	Entertainment Committee	1,934.00
Dues 1918	695.25	House Committee	3,416.44
Dues 1917	207.00	Library	58.78
Dues 1916	107.50	General Society	1,860.83
Dues 1915	51.25	Civil Section	153.33
Dues 1914	12.50	Mechanical Section	151.50
Dues 1908	8.00	M. & M. Section	186.49
Total Dues	$11,361.00	Proceedings	3,181.47
Entrance Fees	$ 635.00		
Advertising	1,473.77		
Proceedings	357.77		
Society Pins	55.00		
Smoker Receipts	243.00		
Dinner for Dr. Walker	254.00		
Boat Excursion	131.25		
Entertainment and Dance	151.50		
Interest	845.82		
Total Receipts	$15,508.11	Total Expenditures	$15,033.07

INVESTMENTS

One $1000 Butler Water Co. 5% Bond No. 9, matures September 2, 1931	$ 1,025.00
Two $1000 Connelsville Water Co. 5% Bonds Nos. 317 and 318, maturing Oct. 1, 1930	2,020.00
Two $1000 Portsmouth, Berkley & Suffolk Water Co. 5% Bonds Nos. 465–466, maturing Nov. 1, 1944	2,000.00
Two $1000 Jamison Coal & Coke Co. 5% Bonds Nos. 1502 and 1503, maturing Nov. 1, 1931	2,000.00
Two $1000 Union Steel Co. 5% Bonds Nos. 33642–33643, maturing Dec. 1, 1952	2,090.00
Two $1000 Pennsylvania Railroad Co. 4½% Bonds Nos. 27320–27321, maturing Aug. 1, 1960	2,070.00
Three $1000 Jones & Laughlin Steel Co. 5% Bonds Nos. 3020–3021–3022, maturing May 1, 1931	2,997.92
One $1000 U. S. Liberty Bond 4¼% No. 54437, maturing September 15, 1928	1,000.00
Total Fifteen Bonds	$15,202.92

ASSETS

	Dec. 31, 1918	Dec. 31, 1919
Permanent Fund—		
Bonds	$15,202.92	$15,202.92
Cash (Fidelity T. & T. Co.)	374.71	874.71
Reserve Fund—		
Cash (Fidelity T. & T. Co.)	2,500.00	2,500.00
General Fund—		
Cash (Diamond National Bank	231.83	206.87
	$18,309.46	$18,784.50
Increase during 1919	475.04	
	$18,874.50	$18,784.50

It may be mentioned that the Water Company's bonds have gained steadily in market value during the year and the Society held its own financially otherwise. It is, of course, understood that the main object of our institution is not to make money, but to take care of the main engineering matters and to provide a home and entertainment for its members.

Respectfully submitted,

A. Stucki, *Treasurer.*

REPORT OF SPECIAL COMMITTEE ON COOPERATION OF LOCAL SECTIONS OF NATIONAL SOCIETIES AND THE ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

The first meeting which I called as chairman of this committee was on November 7th, 1919, and another meeting was held November 18th, 1919. At these meetings some definite suggestions for affiliation, such as joint meetings, for example, were discussed and the general opinion of the committee was strongly in favor of some arrangement of this nature.

However, as the committee was rather large to successfully work out a number of details that at once arise in perfecting such plans, a sub-committee of six was appointed to put into definite shape a plan, which would be submitted to the whole committee for their approval.

The sub-committee has been working on such a general plan which among other things will probably embody the idea of a Pittsburgh Engineering Council, where representatives of National Society Local Sections will meet with us to pass on matters of public interest.

The Sub-Committee expects to finish its work and report back to the main committee in a short time now.

Respectfully submitted,

Sumner B. Ely, *Chairman.*

REPORT OF SPECIAL COMMITTEE ON A NATIONAL DEPARTMENT OF PUBLIC WORKS

To the Board of Direction,

Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Committee on a National Department of Public Works begs to submit the following report of work done during the past year:

Two meetings of the Committee were held and a special meeting of the Society, at which Mr. M. O. Leighton, Chairman, National Department of Public Works Association, was present and gave the Society a detailed account of the object of the establishment of such a department and the benefits to be derived therefrom.

The main committee is composed of twenty-five members who were appointed with the idea of having a member in or near the home of each Representative from the districts included in our territory, in order that they might get in touch with these men asking their support of the Jones-Reavis Bill which was presented in Congress and will be again taken up during the present session.

Letters were written to other members of the Society, enclosing printed list of Representatives, requesting them to write these men asking for their support of the bill.

The replies to date indicate that every Representative in our territory has been written to three or more times and the replies received were about the same.

These replies indicate, without exception, that they are heartily in favor of the bill.

The second Convention of the National Department of Public Works Association was held in Washington, January 13th and 14th, 1920, and this organization was represented by E. F. Wendt, a member of the Society, residing in Washington, and your Chairman.

A meeting of the Committee will be held in the near future to ascertain what further action they can take to aid in this movement.

Respectfully submitted,

MORRIS KNOWLES, *Chairman.*

CIVIC AFFAIRS COMMITTEE REPORT

Engineers' Society of Western Pennsylvania,
Pittsburgh, Pa.:

Dear Sirs:

As to the Annual Report of the Civic Affairs Committee, would advise that during the year, there have been two items of importance come up within their jurisdiction, namely, the matter of Legislation on the proposed licensing of architects by the State of Pennsylvania. This matter was looked into and reported to you, with the recommendation that it be endorsed and that the Society do what they could to assist the architects in securing this licensing bill.

Another matter was the action of our County Commissioners in awarding the design and supervision of the 16th Street and 43rd Street Bridges to firms of architects. This matter was reported upon and proposed action did not meet with the approval of the general meeting of the Society who, by vote, expressed their preference for individual action rather than Society action, so that this matter was dropped by the Committee.

Respectfully submitted,

George H. Danforth,
Chairman, Civic Affairs Committee.

SPECIAL COMMITTEE REPORT ON AWARDING OF CONTRACTS BY COUNTY COMMISSIONERS TO ARCHITECTS

Engineers' Society of Western Pennsylvania,
Pittsburgh, Pa.:

Dear Sirs:

In accordance with the instructions of the Board of Direction, your committee have considered the report of the Civic Affairs Committee on December 16th, 1919, and the discussion which followed relative to the design of county bridges by architects. Through the kindness of the Pittsburgh Association of Members of the American Society of Civil Engineers, we have also had access to the report of its committee, giving a complete statement of the facts in the case, and containing extracts from the contracts between the County Commissioners and the architects.

We now submit the report on the matter and recommend that the following resolution be submitted to the Society:

Whereas, In the design and construction of bridges and similar structures safety to human life, economy in the expenditure of public funds and the traffic needs of the community require that the structural design, inspection of construction and erection and arrangement and development of approaches and street grades should be placed in the hands of competent and experienced engineers, specially skilled and trained for these classes of work; and

WHEREAS, To secure harmonious and artistic results the esthetic treatment and decoration of such structures should be entrusted to skilled architects; and

WHEREAS, The best interests of the community are served by the cooperation of such work of engineers and architects, both responsible to the public officials in charge of the execution thereof; and

WHEREAS, The County Commissioners of Allegheny County have retained architects to design and supervise construction of certain bridges; and

WHEREAS, Although such architects have employed engineers to assist them in the structural design of such bridges, these engineers are not responsible to the County Commissioners except through the architects by whom they are employed; and

WHEREAS, The County Commissioners have in their employ as County Engineer a competent and experienced engineer with an organization skilled and trained in the consideration of bridges and their appurtenances; and

WHEREAS, Section 2 of the Act of May 8, 1919 (P. L. No. 108) requires that "The County engineer . . . shall prepare plans, specifications and estimates of all engineering work undertaken by such county, ..." Therefore, be it

RESOLVED, That the Engineers' Society of Western Pennsylvania earnestly recommend to the County Commissioners:

First. That on all future structures of this kind, the structural design, the inspection of construction and erection, and the arrangement and development of approaches and street grades be recognized, in accordance with the law, as the function of the County Engineer or of other engineers retained as his advisors, and that the esthetic treatment and decoration be entrusted to skilled architects retained as consultants to the County Engineer; and

Second. That in cases where architects have already been retained, the County Commissioners require the County Engineer, or else a competent consulting engineer retained as his advisor, to pass upon the safety and economy of all plans prepared by the engineers employed by such architects. And be it further

RESOLVED, That the Pittsburgh Chapter of the American Institute of Architects be invited to join with the Society in impressing upon the Commissioners and the public the importance of proper cooperation of the two professions on future work of this character. It is further recommended that copies of the resolution as adopted be forwarded to the County Commissioners of Allegheny County, the Mayor and Council of Pittsburgh, the Chamber of Commerce and other local civic bodies, the local sections of the various professional and technical societies, the editors of all local newspapers, and the editors of the technical journals received in the Society's library

Respectfully submitted,

W. G. WILKINS, SAMUEL E. DUFF,
JOHN A. HUNTER, MORRIS KNOWLES,
Chairman.

Mr. Duff moved that the resolution recommended by the Committee be adopted. The motion was seconded and carried by unanimous vote.

REPORT OF CIVIL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the following report of work done by the Civil Section during the year 1919:

Four regular meetings of the Section were held during the year. The average attendance at these meetings was 53; the maximum being 64 at the May meeting and the minimum 41 at the January meeting.

An average of ten participated in the discussion of the several papers presented. The papers were as follows:

January Meeting: "Development of Cast Steel Anchor Chains," by A. E. Crockett, Forging Engineer, Jones & Laughlin Steel Co.

April Meeting: "Construction of Steel Barges," by Thomas Leach, Chief Engineer, Ferguson Steel & Iron Co., Buffalo, N. Y.

May Meeting: "Central Boiler Feed Water Service for Plants," by S. H. McKee, Asst. Chief Engineer, Republic Iron & Steel Co., Youngstown, Ohio.

November Meeting: "Roofing Materials for Industrial Plants," by M. Davis, Manager, H. H. Robertson Co., Pittsburgh, Pa.

Respectfully submitted,
J. H. MINTON, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the following report of work done by the Mechanical Section during the year 1919.

Four regular meetings of the Mechanical Section were held in 1919 with an average attendance of 64, the maximum attendance was 78 at the December meeting, and the minimum 52 at the October meeting. The average number participating in the discussion of papers was seven.

The papers presented were as follows:

February Meeting: "Experiments in Lubrication,' 'by Albert Kingsbury, Consulting Engineer, Pittsburgh.

March Meeting: "Steam Power Plants as Applied to Vehicles for Common Roads," by F L. Egan, Engineer, River Equipment, Carnegie Steel Co., Pittsburgh.

October Meeting: "Notes on Bronze and Babbitt Bearings," by W. K. Frank, V. P. and Gen. Mgr., Damascus Bronze Co., Pittsburgh.

December Meeting: "Superheaters and the Utilization of Superheated Steam," by D. D. Pendleton and C. A. Brandt, Industrial Department, Locomotive Superheater Co., Pittsburgh.

Respectfully submitted,

L. C. Frohrieb, *Chairman.*

REPORT OF METALLURGICAL AND MINING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Four regular meetings of the Metallurgical & Mining Section of the Society were held in 1919, with an average attendance of 106; the maximum attendance being 260 at the March meeting, and the minimum being 32 at the October meeting.

The average number participating in the discussion of the papers was six.

The papers presented were:

January Meeting: "Some Considerations With Regard to Fuel Gas," by Prof. Frederic Crabtree, Professor of Metallurgy, Carnegie Institute of Technology, Pittsburgh.

March Meeting: Joint meeting of M. & M. Section and A. C. S.—"Gas, Smoke and Flame in This War and the Next," by Col. William H. Walker, Chemical Warfare Service, U. S. Army, Baltimore, Md.

October Meeting: "Industrial Applications of Nickel Chromium Alloys," by Mr. W. A. Gatward, Engineer, Hoskins Mfg. Co., Detroit, Mich.

November Meeting: "New Developments in Acid Resisting and Cutting Alloys," by Mr. Elwood Haynes, President, Haynes Stellite Co., Kokomo, Ind.

Respectfully submitted,

George L. Norris, *Chairman.*

REPORT OF TELLERS

To the Members,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The undersigned Tellers publicly canvassed the ballots in the annual election of officers of the Society at noon, Tuesday, January 20th, 1920, and beg to report the following results:

Ballots received	314
Irregular ballots	21
Ballots counted	293

For President	W. C. Hawley	293
For Vice President	H. D. James	291
For Treasurer	A. Stucki	290
For Directors	W. E. Fohl	287
	J. H. Minton	287

Respectfully submitted,

WILLIAM HOOPES
SYDNEY DILLON
W. L. KELLER
Tellers.

The president thereupon declared the following men elected:

For President	W. C. Hawley
For Vice President	H. D. James
For Treasurer	A. Stucki
For Directors	J. H. Minton
	W. E. Fohl

Mr. Neilson requested Past President Duff and Mr. Spellmire to escort the president elect to the chair, who upon assuming the chair addressed the Society as follows:

Gentlemen, I wish to express my sincere appreciation of the honor which you have conferred upon me. When I look at the names of the eminent engineers who have preceded me in this office, I can but realize how far I fall short of measuring up to their standard, but I shall do the best I can and I bespeak your hearty cooperation.

There being no further business before the Society, the paper of the evening on "Searchlights and Searchlight Development" was presented by Mr. S. G. Hibben, Illuminating Engineer, Westinghouse Lamp, Co., Bloomfield, N. J.

The ensuing discussion was participated in by: Walter B. Spellmire, Manager, General Electric Co.; A. E. Blake, Sales Engineer, Surface Combustion Co.; H. L. Beach, Sales Engineer, Clark Car Co.; Samuel E. Duff, Cons. Engr., Pittsburgh, Pa.; D. W. Blakeslee, Elec. Engr., Jones & Laughlin Steel Co., and the author.

On motion the meeting adjourned at 10:22 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, February 5, 1920, at 4:15 P. M., President W. C. Hawley presiding Messrs. Danforth, Schatz, Spellmire, Hunter, Hildner, Ladd, Fohl and the Secretary being present.

The Minutes of the last meeting held January 8th were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Gordon, Harold L. | Hepburn, Peter W.

ASSOCIATE

Brown, Robson L.

JUNIOR

Pontzer, Edward Andrew

The following applications for membership were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Blakeslee, Doraf Wilmot | White, Arthur J.

JUNIOR

Peterson, Elmer J.

Application for transfer to higher grade was received from Mr. R. L. Templin, and after discussion the Board requested that he be transferred to the grade of Associate Member.

Request for reinstatement was received from Mr. F. R. Benson, and the Board requested that a letter be written Mr. Benson advising that his name had been placed on the Society rolls.

Letters of resignation were received from the following gentlemen, and after discussion, they were ordered accepted:

Fiske, H. C.	Schell, W. F.
MacMillan, C. C.	Barras, L. R.
Stearns, E. D.	

The Secretary presented letters of resignation from the following gentlemen, and it was moved and carried that they be turned over to the Membership Committee with the request that they endeavor to secure their consent to withdraw their resignation:

Biggert, J. P.	McCall, C. H.
Hendrix, W. W.	McNeil, Donald
Klingelhofer, W. L.	Semple, J. B.

The Secretary also presented letters of resignation from Messrs. F. L. Garlinghouse, George H. Barbour and N. F. Hopkins, which were held over from the last meeting of the Board. Mr. Hawley reported that he had seen Mr. Hopkins, who had agreed to withdraw his resignation. The Secretary reported in the case of Mr. Barbour, stating that Mr. Neilson had seen him and he had agreed to reconsider the matter and let us know his decision later. No report was received from Mr. Garlinghouse, and the Secretary was requested to call Mr. Wilkins, asking his aid to secure Mr. Garlinghouse's consent to withdraw his resignation.

The report of the Secretary showing the financial condition of the Society at close of business December 31, 1919, was approved, subject to the audit of the Finance Committee, who, owing to change in Chairman has not audited it as yet.

The Secretary retired from the meeting while the election of a secretary for the ensuing year was considered. Kenneth F. Treschow was reelected secretary of the Society at an increase in salary of $50.00 per month.

At the request of the Secretary, Miss Harper, stenographer in the Society's office, received an increase of $10.00 per month in salary.

COMMITTEE REPORTS

Mr. Hawley, Chairman of the Entertainment Committee, reported that the paid attendance at the Annual Banquet held January 26, was 855.

Mr. Schatz, Chairman of the House Committee, reported an evening attendance of 22 for the month of January, as follows:

First week	5
Second week	6
Third week	4
Fourth week	7
	22

The Committee is arranging to have the furniture in the Society rooms gone over and cleaned and any necessary repairs made. Arrangements are also under way for the cleaning and rearranging of our store-room in the basement and work is to start next Monday.

Bids have been received on making two magazine racks, authorized by the Board of Direction some time ago, and the work has been started by the firm quoting a price far lower than any other prices received.

Owing to the appointment of various Chairmen no further committee reports were presented.

The Secretary read a letter from Mr. F. Marshall, Asst. Secretary Chamber of Commerce of Pittsburgh, in regard to the adoption of the compulsory metric system. It was moved and carried that it be referred to the Civic Affairs Committee with request that they report at the next meeting of the Board.

The Secretary also presented a letter from Mr. M. O. Leighton, Chairman, National Service Committee, in regard to the Boston-Washington Super-Power Investigation.

After discussion it was moved and carried that the matter be referred to the Civic Affairs Committee with the request that they look into the matter and report to the Board of Direction at its next meeting.

On motion the meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The Annual Meeting of the Mechanical Section of the Eengineers' Society of Western Pennsylvania, was held in the Society Rooms, Union Arcade Building, Tuesday, February 3, at 8:00 P. M. Mr. A. L. Hoerr, acting as chairman, due to illness of chairman, 74 members and visitors being present.

The Minutes of the last annual meeting held February 4, 1919, were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was read by the Secretary, as follows:

Officers and Members of the Mechanical Section
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Nominating Committee have selected the following men as officers for the Mechanical Section for the ensuing year:

Chiarman	George T. Ladd
Vice Chairman	J. C. Hobbs
Directors	M. R. Maclean Kenneth Seaver M. R. Stevenson W. O. Brosius L. K. Yoder

Respectfully submitted,

H. A. Rapelye,
G. E. Flanagan,
J. D. Hiles,
Tellers.

On motion nominations were closed and the Secretary was instructed to cast a unanimous ballot in favor of the officers named, and they were, therefore, declared elected.

There being no further business the meeting adjourned and the regular bi-monthly meeting was called to order by Mr. Hoerr in the absence of the new Chairman, Mr. George T. Ladd.

The Minutes of the last bi-monthly meeting of the Section held December 3, 1919, were read and approved.

No further business coming before the Section, the paper of the evening on "Powdered Coal" was presented by Mr. John E. Muhlfeld, Vice-President, Railway & Industrial Engineers, New York City.

The ensuing discussion was participated in by: A. L. Hoerr, Chf. Engr., National Tube Co., McKeesport, Pa.; W. E. Symonds, Cons. Engr., Galena-Signal Oil Co., New York City; J. H. Richardson, Struct. Engr., Ford, Bacon & Davis, New York City; O. P. Hood, Chf. Mech. Engr., U. S. Bureau of Mines, Washington, D. C.; A. E. Blake, Sales Engr., Surface Combustion Co., Pittsburgh, and the author.

On motion duly seconded, a unanimous vote of thanks was extended to Mr. Muhlfeld for his very interesting and instructive paper.

The meeting adjourned at 10:00 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 383rd Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, February 17, at 8:15 P. M., President W. C. Hawley presiding, 148 members and visitors being present.

The Minutes of the last regular meeting held December 16, 1919, were read and approved.

The Board of Direction reported the election of two applicants to the grade of Member, one to the grade of Associate, and one to the grade of Junior, and the receipt of three applications for membership. One application was received for reinstatement, and one for transfer to higher grade.

There being no further business, the paper of the evening on "Waste Heat Boilers" was presented by Dr. D. S. Jacobus, Advisory Engineer, Babcock & Wilcox Co., New York, N. Y.

The ensuing discussion was participated in by: M. F. McConnell, Supt., Mingo Works, Carnegie Steel Co., Steubenville, Ohio; F. E. Leahy, Fuel & Expr. Engr., Carnegie Steel Co., Duquesne, Pa.; Lewis Vincent, Cons. Gas Engr., Pittsburgh; Grant D. Bradshaw, Pres., Andrews-Bradshaw Co., Pittsburgh; J. R. Mason, Dist. Mgr., Wickes Boiler Co., Pittsburgh; John A. Hunter, Steam & Sanitary Engr., American Sheet & Tin Plate Co., Pittsburgh; G. C. Emmons, Eff. Engr., Republic Iron & Steel Co., Youngstown, O.; H. C. Cronemeyer, Designer, Jones & Laughlin Steel Co., Woodlawn, Pa.; E. G. Helander, and the author.

It was moved and seconded and carried unanimously that a vote of thanks be extended to Dr. Jacobus for his very excellent paper.

On motion the meeting adjourned at 9:35 P. M.

K. F. Treschow, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, March 4, at 4:15 P. M., President W. C. Hawley presiding, Messrs. Danforth, James, Minton, Spellmire, Fohl, Hunter, Holdner and the Secretary being present.

The Minutes of the last regular meeting held February 5, were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board were elected to membership:

MEMBERS

Blakeslee, Doraf Wilmot
White, Arthur J.

JUNIOR

Peterson, Elmer G.

The following applications for membership were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Bennett, Charles Wilbur
Cline, John Russell
Dempler, George P.
Frazier, Chauncey E.
Gass, Karl William
Masters, William C.
Merz, Paul Caesar
Tegge, Albert R.

Applications for transfer to higher grades were received from the following gentlemen and after discussion, the Board requested that they be transferred to the grade of Member:

J. W. W. Hallock
C. H. McCall
C. J. Schmalzried

Letters of resignation were received from the following gentlemen and it was moved and carried that they be accepted:

A. E. Abel..Joined Jan. 1911
J. P. Biggert....................................Joined April 1903
J. W. Dougherty.............................Joined Dec. 1916
F. L. Garlinghouse.........................Joined Jan. 1904

The Secretary presented letter from T. Philipsen, who made application for membership in December, 1918, stating that shortly after having been elected, he had sickness in his family and had not been able to complete his matriculation or pay dues for 1919 and 20. After discussion, it was moved and carried that the Secretary be requested to write Mr. Philipsen, stating that as he never matriculated, his application would be considered as having been withdrawn and would be held in the office until such time as he felt able to renew his application.

Letter was also presented from Mr. A. F. Allard, stating that he had resigned in 1915 or 1916. His name had never been removed from the rolls and he asked that some concession be made in his dues, as he had not received PROCEEDINGS and had been practically out of touch with the Society and its work. After discussion, it was moved and carried that the Secretary be requested to write him and advise that in view of the circumstances, the Board had remitted his dues for the years 1915, 16 and 17.

The Secretary reported the death of the following gentlemen:

J. A. Atwood	Joined April 1891	Died Mar. 1, 1920
W. H. Lauman	Joined Oct. 1913	Died Feb. 28, 1920
Dr. F. C. Phillips	Joined Jan. 1880	Died Feb. 16, 1920

The Secretary was requested to secure a Memoir of Mr. Atwood from Mr. A. R. Raymer and for Dr. Phillips from some one from the University of Pittsburgh.

The Secretary presented a letter of resignation from Mr. H. D. Wilson resigning from the Board of Direction. After discussion, it was moved and carried that Mr. Wilson's resignation be accepted with regret.

Mr. Hawley, President, called for nominations to fill the vacancy and Mr. F N. Speller was nominated and unanimously elected subject to his consent to serve. Mr. James agreed to see Mr. Speller and endeavor to secure his consent.

The reports of the Secretary showing the financial condition of the Society at close of business December 31, 1919, and January 31, 1920, having been regularly audited by the Finance Committee, were approved.

COMMITTEE REPORTS

Mr. Fohl, Chairman of the Civic Affairs Committee, reported on the various matters referred to the Committee by the Board of Direction as follows:

Communication from the World Trade Club in regard to the adoption of the Metric Standardization of Weights and Measures. The Committee recommended to the Board that the Engineer's Society take no action,

in view of the lack of knowledge and the inaccuracy of the statements of the sponsors, the World Trade Club, and in view of the recent resolution, copy of which was sent to the Society, of the Chamber of Commerce, whose committee on Trade and Commerce, after going into the matter very thoroughly, opposed the adoption of compulsory Metric System. It was further stated that two members of the Committee, whose companies do business with Nations abroad using the Metric System, that they found there was absolutely no difficulty in translating from the Metric System to American measurements.

After discussion, it was moved and carried that the report of the Committee be accepted as read.

Mr. Minton, Chairman of the Finance Committee, reported that Mr. Paul S. Whitman and Mr. W. K. Frank had been appointed to serve on the Finance Committee for the ensuing year.

The books of the Society for the months of December, 1919, and January, 1920, have been checked and approved.

Mr. James, Chairman of the Entertainment Committee, reported verbally stating that no meetings of the committee had been held during the past month, but he expected to call a meeting in the near future.

The Secretary read the report of the House Committee in the absence of Mr. Schatz, Chairman.

Evening attendance for month of February 21. The Storeroom of the Society in the basement has been cleaned out and all back files of PROCEEDINGS rewrapped.

The committee still has in mind the matter of quarters and hopes to have something definite to report to the Board at a future meeting.

Mr. Hunter, Chairman of the Membership Committee, reported the following gentlemen were to serve on the Membership Committee for the ensuing year:

John A. Hunter, Chairman

C. A. Bercaw
L. B. Duff
W. L. Keller
C. M. Reppert
C. J. Schmalzried

The six letters of resignation referred to the committee were investigated with the following results:

J. B. Semple, in Florida until May 1.
W. L. Klingelhofer, resignation withdrawn.
C. H. McCall, resignation withdrawn.
Donald McNeil, resignation withdrawn.
J. P. Biggert, resignation final.
W. W. Hendrix, will reconsider.

Mr. Spellmire, Chairman of the Publication Committee, reported that appointments on the Publication Committee for the ensuing year would be completed next week, when the first meeting of the committee would be called.

The Secretary presented a letter and resolution adopted by the Council of the American Institute of Consulting Engineers, condemning action taken by the County Commissioners in awarding contracts for the design and construction of the 16th and 43rd Street bridges to architectural firms.

The meeting adjourned at 5:30 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, March 2, at 8:15 P. M., Chairman L. F. W. Hildner presiding, 76 members and visitors being present.

The Minutes of the last meeting held January 6 were read and approved.

There being no further business before the Section, the paper of the evening on "Surface Combustion" was presented by Mr. A. E. Blake, Sales Engineer, Surface Combustion Company, Pittsburgh.

Written discussion was received from W. Trinks, Professor, Mechanical Engineering, Carnegie Inst. of Technology; A. F. Mitchell, Supt. Heat Treatment, U. S. Naval Ordnance Plant, S. Charleston, W. Va.

The ensuing discussion was participated in by: Kirtland Marsh, Pyrometry Engr., Aluminum Co. of America; Wilbert J. Huff, Research Chemist, U. S. Bureau of Mines; G. D. Bradshaw, Pres., Andrews-Bradshaw Co.; Edward Rahm, Jr., Sales Engr., Underfeed Stoker Co. of America; H. M. Van Deventer, National Tube Co.; E. E. Ross, Service Engr., Auto Equipment Dept., Westinghouse Elec. & Mfg. Co.; F. F. Espenscheid, Engr., W. E. Moore & Co.; W. J. Merten, Met. Engr., Westinghouse Elec. & Mfg. Co.; S. G. Brigel, Mgr., Economy Burner & Engrg. Co.; Thomas Turnbull, Jr., Director, Tate-Jones & Co.; H. P. Smith, Power Engr., McClintic-Marshall Co.; H. L. Abramovitz, Chemist, Philadelphia Co.; Lauson Stone, Jones & Laughlin Steel Co., and the author.

On motion the meeting adjourned at 10:08 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The 384th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, March 16th, at 8:25 P. M., 26 members and visitors being present.

The Minutes of the last regular meeting held February 17 were read and approved.

The Board of Direction reported the election of two applicants to the grade of Member and one to the grade of Junior and the receipt of eight applications for membership and transfer of three members to the grade of Member.

There being no further business, the paper of the evening on "Grinding Wheels—Uses, Manufacture and Selection," was presented by Wallace T. Montague, Sales Engineer, The Norton Co., Worcester, Mass.

The ensuing discussion was participated in by E. C. Brandt, Supervisor Equipment & Methods, Westinghouse Elec. & Mfg. Co.; A. E. Blake, Sales Engr., Surface Combustion Co.; Walter B. Spellmire, Mgr., General Electric Co., and the author.

Mr. Hawley extended the thanks of the Society for the very excellent paper presented by Mr. Montague.

On motion the meeting adjourned at 9:36 P. M.

K. F. TRESCHOW, *Secretary.*

METALLURGICAL & MINING SECTION

ANNUAL MEETING

The Annual Meeting of the Metallurgical & Mining Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade, Tuesday, March 30, 1920, at 8:28 P. M., Mr. Walter B. Spellmire presiding in the absence of the Chairman, 68 members and visitors being present.

The Minutes of the last annual meeting held January 28, 1919, were read and approved.

The annual report of the chairman was read by the Secretary.

The report of the Nominating Committee was presented by Dr. John S. Unger, Chairman:

*To Officers and Members Metallurgical & Mining Section,
Engineers' Society of Western Pennsylvania:*

Dear Sirs:

Your Nominating Committee have selected the following gentlemen for the officers for the Section for the ensuing year:

J. W. Paul..Chairman
H. P. Tiemann......................................Vice Chairman
G. M. Goodspeed
N. F. Hopkins
H. H. Rankin
H. McW. Cadman
W. A. Weldin
....Directors

Respectfully submitted,

J. S. Unger,
A. W. Patton,
W. L. Affelder,
Nominating Committee.

On motion the nominations were closed and the Secretary was requested to cast a unanimous ballot in favor of the election of the officers named, who were thereupon duly declared elected.

On motion the meeting adjourned at 8:50 P. M. and the regular bimonthly meeting was called to order.

The Minutes of the last regular meeting held January 28 were read and approved.

No further business coming before the Section, the paper of the evening on "Mine Hoisting—Duty Cycles," was presented by Mr. M. A. Whiting, Engineering Department, General Electric Co., Schenectady, N. Y.

The ensuing discussion was participated in by: F. W. C. Bailey, Cons. Engr., Pittsburg Coal Co., Columbus, O.; G. G. Bell, West Penn Railways Co.; Joseph Breslove, Cons. Engr.; Graham Bright, Engr., Mining Dept., Westinghouse Elec. & Mfg. Co.; Robert Linton, Cons. Mining Engr., New York, N. Y.; G. B. Mann, Sales Engineer, Dravo-Doyle Co.; R. M. McNeil, Gen. Engr., Westinghouse Elec. & Mfg. Co.; Walter B. Spellmire, Mgr., General Electric Co.; F. L. Stone, Elec. Engr., General Electric Co., Schenectady, N. Y.; John S. Unger, Mgr., Central Research Bureau, Carnegie Steel Co., and the author.

It was moved, carried and passed unanimously that a vote of thanks be tendered Mr. Whiting for his very interesting paper.

No further business coming before the Section, the meeting adjourned at 10:33 P. M.

K. F. Treschow, *Secretary.*

O.K.

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, April 1, 1920, at 4:15 P. M., President W. C. Hawley presiding, Messrs. Snyder, Neilson, James, Danforth, Hunter, Speller, Schatz, Ladd, Hildner, Paul and the Secretary being present.

The Minutes of the last meeting held March 4, were read and approved.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Bennett, Charles Wilbur
Cline, John Russell
Dempler, George P.
Frazier, Chauncey E.
Gass, Karl William
Masters, William C.
Merz, Paul Caesar
Tegge, Albert R.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Allen, Hugh Pendleton
Beeken, Alfred D., Jr.
Buell, William C., Jr.
Rovegno, Peter Stephen
Slater, Homer B.

ASSOCIATE MEMBER

Wilson, William Satterlee

JUNIOR

Wolf, Morris L.

The report of the Secretary showing the financial condition of the Society at the close of business February 29th, 1920, having been regularly audited by the Finance Committee, was approved.

Mr. James, Chairman of the Entertainment Committee, reported that one meeting had been held during the month at which various forms of entertainment were discussed and a tentative program laid out for the balance of the year. The following entertainments and inspection trips are listed as follows:

Visit to Carnegie Institute of Technology to witness play some night latter part of April.

Inspection trip to LaBelle Works, Steubenville, Ohio, the latter part of April.

Dinner-dance, Hotel Chatham, Friday evening, May 7.

Boat Excursion the early part of June.

Several other trips are being arranged, also other entertainments to be held during the Summer and Fall.

Mr. Minton, Chairman of the Finance Committee, reported that in compliance with instructions of the Board at the March 4 meeting, letters were written to the seven men who had not paid their dues for the years 1914 to date, with the following results : One man paid in full; one paid in part and promised to pay in full; three promised to pay, and two made no reply whatever to the Secretary's letters.

It is recommended that the men who promised to pay be carried on the rolls of the Society, and that the two men who made no reply be dropped from the rolls in accordance with the By-Laws.

After discussion it was moved and carried that the report of the Committee be approved and action taken as suggested therein.

Mr. Schatz, Chairman of the House Committee, reported an evening attendance of 35 for the month of March. He stated that the committee felt our present quarters were very well located, but that there should be a re-arrangement so that the Society Rooms and Auditorium might be together. The Committee have been working along these lines for some time past, when the death of Mr. Frick stopped negotiations for the present. Mr. Schatz stated he would like an expression from the Board as to whether they thought it desirable to remain in this building or if they could suggest any other arrangements.

After discussion it was moved and carried that the Committee be authorized to work along the lines suggested in their report as it was the opinion of the Board that it is desirable, if possible, to remain in this building.

Mr. Hunter, Chairman of the Membership Committee, reported that the Committee held a meeting March 16 to discuss ways and means of increasing the membership. Several ideas were advanced for bringing before the engineers of Pittsburgh the advantage of affiliating themselves with the Society, but nothing definite was evolved in the way of recommendations at this time.

The Committee also recommended for the consideration of the Board the formation of a Students' Section. It was thought that this section would draw its membership from students who are attending the Univer-

sity of Pittsburgh, Carnegie Institute of Technology and the men in the Apprenticeship Courses at the Westinghouse Electric & Manufacturing Company.

After discussion it was moved and carried that the Committee be authorized to endeavor to form a Student Section of the Society.

Mr. Hawley called on Mr. Ely, Chairman of the Special Committee on Society Affiliation, to make his report to the Board of Direction. Mr. Ely stated that in accordance with instructions from the Board about a year ago the Committee had endeavored to make plans for a closer relationship between the various local chapters of the National Societies and the Engineers' Society of Western Pennsylvania.

Shortly after the Committee commenced its work, a movement was started in New York for the formation of a National Council and the Committee felt that it would be better to follow the plans being worked out in New York and accordingly made up the proposed regulations for the Associated Engineering Societies in Pittsburgh, which at the last meeting of the Committee were adopted and the Chairman authorized to present his report to the Board of Direction of the Engineers' Society for its consideration.

After discussion it was moved and carried that the report be received and the President authorized to call a special meeting of the Board for Wednesday evening, April 7, to consider and act upon the proposed regulations.

Mr. Hawley read a letter from Mr. Ely, Chairman of the Pittsburgh Section of the American Society of Mechanical Engineers, asking permission of the Board of Direction to have Mr. Treschow act as Secretary of their section.

After discussion it was moved and carried that Mr. Ely's request be approved as it was felt this was a step in the right direction towards closer affiliation with the local societies.

On motion the meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

SPECIAL MEETING OF BOARD OF DIRECTION

A special meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Wednesday, April 7, at 7:45 P. M., President W. C. Hawley presiding, Messrs. James, Minton, Hildner, Danforth, Ladd, Fohl, Snyder, Schatz and the Secretary being present.

Mr. Hawley stated that the meeting had been called to discuss and act upon the following report of the Special Committee on Society Affiliation appointed about a year ago, which was presented at the last meeting of the Board of Direction.

PROPOSED REGULATIONS OF THE ASSOCIATED ENGINEERING SOCIETIES OF PITTSBURGH

COMPOSED OF

Engineers' Society of Western Pennsylvania,
Pittsburgh Association of Members, American Society of Civil Engineers,
Pittsburgh Section, American Society of Mechanical Engineers,
Pittsburgh Section, American Institute of Electrical Engineers,
Pittsburgh Section, American Chemical Society,
Pittsburgh Association of Members, American Institute of Mining and Metallurgical Engineers.

ARTICLE I

NAME

Section 1. The name of the Association shall be the Associated Engineering Societies of Pittsburgh, hereinafter referred to as the Association.

Section 2. With the Engineers' Society of Western Pennsylvania the local organizations of the American Society of Civil Engineers, American Society of Mechanical Engineers, American Chemical Society, American Institute of Electrical Engineers, and American Institute of Mining and Metallurgical Engineers are charter affiliated organizations of the Association. Other engineering organizations are eligible for affiliation.

ARTICLE II

AIMS AND OBJECTS

Section 1. The object of the Association shall be the cooperation of Engineering Societies of Pittsburgh.

Section 2. In furtherance of the spirit of the Engineers' Society of Western Pennsylvania which prompts it to offer its club rooms in order to promote local united engineering activities, each affiliated organization shall encourage its members to join the Society in order that they may gain social relationship with, local professional standing among, and personal friendship of fellow engineers in Pittsburgh. The Engineers' Society of Western Pennsylvania shall encourage its members to join the National Engineering body through an affiliated organization. It is further recommended that all organizations belonging to the Association shall recom-

mend to their respective sections that an arrangement be made with the Engineers' Society of Western Pennsylvania whereby all secretarial work such as printing and mailing of notices, arranging for meetings, etc., be done through the office of the Engineers' Society of Western Pennsylvania and that all individual meetings of the different organizations be held in the Auditorium of the Society. It is believed that this would aid greatly in uniting the engineering activities in this district.

Section 3. The Engineers' Society of Western Pennsylvania having an auditorium, library, club room, employment bureau, entertainments, bulletin for news items, journal for publication of technical papers and the services of a paid secretary, is recognized as the parent engineering society of Pittsburgh.

ARTICLE III

COUNCIL

Section 1. The affairs of the Association shall be conducted by a Council consisting of the President and two other members of the Board of Direction, preferably two Junior past presidents, of the Engineers' Society of Western Pennsylvania, together with two other Councilors chosen by each of the affiliated organizations, one each year for a term of two years, at least one of whom shall be a member of its governing committee or Board.

Section 2. The President of the Engineers' Society of Western Pennsylvania shall be chairman of the Council. In his absence the Council shall choose a chairman *pro tem*. The Secretary and Treasurer of the Engineers' Society of Western Pennsylvania shall act in similar capacities for the Council.

Section 3. Meetings of the Council may be held upon call of any two Councilors, but not less than four per year upon call of the Chairman. A majority of the members of the Council representing not less than half of the affiliated organizations shall constitute a quorum. The yea and nay vote of members on all questions shall be recorded. Decision of the Council shall require a majority vote of those present.

Section 4. The Council shall have jurisdiction over all matters of joint interest insofar as its decision shall not conflict with the rules of the various affiliated organizations.

Section 5. The Council shall act upon all petitions for affiliation received from other organizations and its decisions shall be printed in the notice for the next meeting of the Association.

Section 6. No individual organization of the Association shall act upon any local public matter, except to refer it to the Council, until the Council has considered and taken action upon it. If the Council's action is to refer it to the Association, no action shall be taken by any individual

organization of the Association until final action has been taken by the Association. The Council may refer such a matter to a meeting of the Association or may order a referendum ballot.

SECTION 7. In National public affairs, recommendations of the Council, if any, shall be printed in the notice for the next meeting of the Association. A majority vote of Council may decide to refer the question to the consideration of one or more of the National Engineering Bodies through their affiliated societies or to the National Council.

ARTICLE IV

MEETINGS

SECTION 1. The Council shall at its discretion call meetings of the Association.

SECTION 2. Each corporate member of the affiliated organizations shall be entitled to a vote at meetings of the Association.

SECTION 3. The Auditorium of the Engineers' Society of Western Pennsylvania shall be available for all meetings of the Association. The order of business at these meetings shall be as follows: Call to order by Chairman of Council; reading of the minutes; reading of Council minutes; unfinished business; new business; presentation of subject; discussion; adjournment.

ARTICLE V

FINANCES

SECTION 1. The regular expenses of the Association shall be as follows: Rent of auditorium, secretary's services, stenographic services, printing, postage, etc. Any additional items of expense shall be considered special.

SECTION 2. Statements of account shall be rendered quarterly by the Secretary. An affiliated organization failing in its obligations shall be notified in writing by the Council and if such obligations are not met within three months thereafter, such organization will be dropped from the Association, upon a vote of a majority of the Council by letter ballot. Any organization may withdraw from the Association three months after service of written notice to the Council provided it is not financially in arrears.

ARTICLE VI

YEAR BOOK

SECTION 1. A year book shall be published in October of each year and shall have as the title on the front cover:

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA AND ASSOCIATED ENGINEERING SOCIETIES OF PITTSBURGH

SECTION 2. The Engineers' Society of Western Pennsylvania and each affiliated organization shall have equal privileges irrespective of the number of members. Each Society may publish: List of officers, list of committees, alphabetical list of members; local constitution and By-Laws; qualifications for and privileges of membership; amount of dues.

The Association shall include its regulations, names of Councilors, annual report of the Chairmen of the Council and other matters of general interest.

SECTION 3. Each organization shall pay its pro rata share of the cost of publication based on number of pages used.

ARTICLE VII

REVISIONS

SECTION 1. These regulations may be amended by the Council, subject to approval of a majority vote of the Association at a subsequent meeting.

The report was then presented for discussion and the Secretary requested to read each article and section separately so that amendments might be made and the report passed upon as read.

After discussion it was moved and carried that the report be approved with the following corrections and referred back to the committee for their consideration.

SECTION 3, ARTICLE 3. Sentence to be added at end of present section: "Except as provided for in Section 5 of this article."

SECTION 5, ARTICLE 3. Changed to read as follows: "Council shall act upon all petitions for affiliation received from other organizations and its decision shall be printed in the notice for the next meeting of the Association." Such petitions shall be proposed at a regular meeting of the Council and voted on at a subsequent meeting; a two-thirds affirmative vote of the total membership of Council being required to elect.

SECTION 1, ARTICLE 7. Last four words of this section to be omitted.

On motion the meeting adjourned at 10:30 P. M.

K. F. TRESCHOW, *Secretary.*

MECHANICAL SECTION

The regular Bi-monthly Meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, April 6th, at 8:20 P. M., Chairman George T. Ladd presiding, 107 members and visitors being present.

The Minutes of the last meeting held February 3 were read and approved.

No further business coming before the Section the paper of the evening was presented on "Power Plant Instruments and Meters," by Mr. E. G. Bailey, President, Bailey Meter Co., Cleveland, O.

The ensuing discussion was participated in by: A. Marsh; F. C. Cone, Salesman, General Electric Co.; C. J. Fechheimer, Research Engr., Power Engineering Dept., Westinghouse Elec. & Mfg. Co.; Walter B. Spellmire, Mgr., General Electric Co.; A. A. Straub, Cons. Engr., Pittsburgh; J. E. Tutein, Steam Dept., South Side Works, Jones & Laughlin Steel So.; H. H. VanDeventer, National Tube Co., and the author.

It was moved and carried that a vote of thanks be extended to Mr. Bailey for his very excellent paper.

On motion the meeting adjourned at 10:32 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 385th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade, Tuesday evening, April 20, at 8:17 P. M., President W. C. Hawley presiding, 197 members and visitors being present.

The Minutes of the last regular monthly meeting held March 16 were read and approved.

The Board of Direction reported the election of eight applicants to the grade of Member and the receipt of seven applications for membership.

No further business coming before the Society, the papers of the evening were presented on "The Present Status of the Theory of the Rolling Mill," by Prof. W. Trinks, Professor, Mechanical Engineering, Carnegie Institute of Technology, and "Bureau of Rolling Mill Research," by Mr. W. B. Skinkle, Director, Bureau of Rolling Mill Research, Carnegie Institute of Technology.

Written discussion was presented by: N. A. Doyle, V. P., American Car and Foundry Co., New York City; S. N. Holstein, Supt., Blooming and Bar Mills, American Rolling Mill Co., Middletown, O.

Owing to the lateness of the hour, there was no oral discussion of the papers.

On motion the meeting adjourned at 10:35 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, May 6, at 4:20 P. M., President W. C. Hawley presiding, Messrs. Neilson, Danforth, Stucki, Minton, Schatz, Hunter, Spellmire, Fohl, Hildner, Speller and the Secretary being present. present.

The Minutes of the last regular meeting held April 1 and of the special meeting held April 7, were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Allen, Hugh Pneldeton
Beeken, Alfred D., Jr.
Buell, William C., Jr.
Rovegno, Peter Stephen
Slater, Homer H.

ASSOCIATE MEMBER

Wilson, William Satterlee

JUNIOR

Wolf, Morris L.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Crolius, Frederick Joseph
Enebuske, Viking
FreeQman, Jonathan Whitehouse
Hagenauer, Nikolaus
Haines, J. Edgar
Hord, Peyton R.
Lauman, August H., Jr.
Peirce, E. Converse
Rodgers, James Franklin
Stewart, William H.
Watts, Joseph
Witmer, Charles Kendrick

The Secretary presented letters of resignation from the following gentlemen, and after discussion they were ordered accepted:

Craig, G. B.
Peck, George L.
Reynders, A. B.
Semple, J. B.

The Secretary reported the death of the following members:

	Joined	Died
Dr. John A. Brashear	Mar., 1884	Apr. 9, 1920
C. W. Johnson	Feb., 1918	
L. H. Martell	Nov., 1907	Jan. 13, 1919
H. A. Porterfield	Nov., 1912	Feb. 8, 1920

It was moved and carried that the President be authorized to appoint a committee to prepare a suitable memoir of Dr. Brashear.

Mr. Hawley requested the Secretary to read a letter received from Dr. Brashear shortly before his death, thanking the Society for the flowers that had been sent him. It was moved and carried that a photostat be made of the letter in order that it might be framed and hung in the Society Rooms.

Mr. Hawley further stated that the Secretary had written the Engineers' Club of Dayton, in regard to a photograph that had been taken of Dr. Brashear (considered the best taken in recent years), inquiring as to price, size, etc.

It was moved and carried that the Secretary be authorized to purchase such a photograph for framing.

The report of the Secretary showing the financial condition of the Society at the close of business March 31, 1920, having been regularly audited by the Finance Committee, was approved.

The report of the Medal Awards Committee was presented as follows:

April 15, 1920.

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Medal Awards Committee has gone very carefully over the papers presented by members of the Society during the past year, and are of the unanimous opinion that the Silver Medal should be awarded to Mr. A. E. Crockett, for his paper on "Cast Iron Anchor Chains."

Your Committee is of the opinion that the papers presented during the last year, while they show careful preparation and were all of great interest, were not of the standard which was necessary for the receiving of the Gold Medal.

Yours very truly,

G. H. Neilson, Chairman;
A. Stucki,
G. H. Danforth,
Medal Awards Committee.

It was moved and carried that the report of the Committee be accepted and the Secretary instructed to have the medal made as soon as possible and presented at a subsequent meeting in accordance with the By-Laws.

COMMITTEE REPORTS

In the absence of Mr. James, Chairman of the Entertainment Committee, the Secretary reported verbally stating that arrangements were complete for the Dinner-Dance Friday evening, May 7, and arrangements were under way for an informal dinner to be given at the Hotel Schenley, May 15, in honor of the French Economic Mission, which is visiting the United States as a guest of the War and Navy Department and the Committee urge that all members of the Board attend this dinner if possible, in order that they might make a good showing for the visitors.

The attendance at the Inspection Trip to Follansbee, was 84.

Mr. J. H. Minton, Chairman of the Finance Committee, reported that the Finance Statement for the month of March was checked and approved.

In reference to the seventeen men who made application for membership in 1917 and prior thereto, and only paid $5.00, these men were notified that unless their dues were paid by May 1, they would be dropped from the Rolls. No response having been received, their names have been dropped from the Rolls of the Society.

There are a number of men in arrears for 1917 to date, and it is proposed to send them regular notifications and if no results are obtained, the Committee will make recommendations with reference to these men in the Fall.

Mr. Schatz, Chairman of the House Committee, reported an evening attendance for the month of April of 26.

Mr. Schatz further reported to the Board that a Meeting of the House Committee was held early in April at which Mr. Shaw, Renting Agent for the Frick Buildings, and Mr. Callender, Superintendent of the Union Arcade, were present to discuss a plan suggested by Mr. Shaw for the Engineers' Society to use the auditorium in the Chamber of Commerce Building, for the remainder of the time our lease runs. It was the consensus of opinion that such a move would be impracticable, unless there was some counter proposition put forth by Mr. Shaw, whereby we might secure more adequate quarters at the end of our present lease, and the Committee requested Mr. Shaw to put such a suggestion in writing to be presented before the next meeting of the Board.

This letter was received and a meeting held on Thursday, May 6, at 3:30 P. M. It was the unanimous opinion of the Committee that the suggestions presented disregarded our original request and they recommend that we do not accept Mr. Shaw's proposition.

After discussion, it was moved and carried that the report of the Committee be accepted and the Secretary requested to write Mr. Shaw, stating that the Board could not comply with his request in his letter of May 6,

also that they respectfully called attention to our present lease and asked that he take immediate steps to provide us with a suitable auditorium in accordance with the third and fourth paragraphs.

Mr. W. B. Spellmire, Chairman of the Publication Committee, reported that appointments had been made on his committee as follows:

A. F. Backlin	J. M. Graves
G. D. Bradshaw	L. F. W. Hildner
J. R. Buchanan	W. R. Jarvis
Frederic Crabtree	George T. Ladd
Thomas Fleming, Jr.	J. W. Paul

and that these gentlemen had agreed to serve.

The first meeting of the committee will be called within the next two weeks.

The Secretary presented an invitation to the Engineers' Society of Western Pennsylvania from the Joint Conference Committee of the four national societies to attend an Organizing Conference to be held in Washington, D. C., June 3 and 4, 1920. This is to be a conference of representatives of national, local, state and regional organizations to discuss a proposed plan of organization which has been prepared by the Joint Conference Committee for the purpose of effecting cooperation of engineering and allied technical organizations to further public welfare wherever technical knowledge and engineering training are involved; and to consider matters of common interest to these professions.

After discussion it was moved and carried that the Secretary be instructed to attend this Joint Conference as an authorized representative of the Society.

The meeting adjourned at 5:20 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION

The Regular Bi-Monthly Meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday evening, May 4, at 8:20 P. M., Vice Chairman L. P. Blum presiding in the absence of the chairman, 76 members and visitors being present.

The Minutes of the last meeting held March 2, 1920, were read and approved.

No further business coming before the Section, the paper of the evening was presented by Mr. George A. Sherron, Eastern Manager, Keehring Machine Co., Philadelphia, on "Modern Concrete Road Construction, Machinery and Methods."

The ensuing discussion was participated in by: J. P. Leaf, City Engineer, Beaver Falls, Pa.; Edward Brogan, Contractor, Pittsburgh; Israel R. Burt, Department Superintendent, National Tube Co., Ellwood City, Pa.; Louis P. Blum, Blum, Weldin & Co., Pittsburgh; Edward F. Hirsch, Student, Carnegie Institute of Technology, Pittsburgh, and the author.

It was moved, seconded and carried unanimously that a vote of thanks be extended to the author for his very interesting paper.

On motion the meeting adjourned at 10:55 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 386th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, May 18, at 8:20 P. M., President W. C. Hawley presiding, 75 members and visitors being present.

The Minutes of the last meeting held April 20 were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member, one to the grade of Associate Member, and one to the grade of Junior, and the receipt of twelve applications for membership. Four resignations were received and accepted.

No further business coming before the Society, the papers of the evening on "Comparative Economics of Continuous and Non-Continuous Trusses" and "Comparative Economics of Wire Cables and High Alloy Steel Eye Bar Cables for Long Span Suspension Bridges," were presented by Dr. J. A. L. Waddell, Waddell & Sons, Consulting Engineers, Kansas City, Mo.

The ensuing discussion was participated in by: J. G. Chalfant, County Engr., Allegheny County, Pittsburgh; Elmer K. Hiles, Mgr. of Laboratories, Pittsburgh Testing Laboratory; James S. Martin, Structural Steel & Concrete Designer, Duquesne Light Co.; E. W. Pittman, Gen. Mgr., Dravo Contracting Co.; C. B. Pyle, Mgr. Erection, McClintoc-Marshall Co.; A. C. Stalknecht, Proprietor, U. S. A. Grease Co.; A. Stucki, Cons. Engr., Pittsburgh; H. R. Thayer, Assoc. Prof., Structural Design, Carnegie Institute of Technology; Willis Whited, Engr. of Bridges, State Highway Dept., Harrisburg, Pa.; Paul L. Wolfel, Chf. Eng., McClintoc-Marshall Co., and the author.

It was moved and carried unanimously that a vote of thanks be extended to Dr. Waddell for his very excellent and interesting papers.

On motion the meeting adjourned at 10:25 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade, Tuesday, June 17 at 4:15 P. M., President W. C. Hawley presiding, Messrs. Danforth, James, Minton, Schatz, Spellmire, Hunter, Speller, Hildner, Snyder, Fohl, and the Secretary being present.

The Minutes of the last regular meeting held May 6 were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Crolius, Frederick Joseph
Enebuske, Viking
Freeman, Jonathan Whitehouse
Hagenauer, Nikolaus
Haines, J. Edgar
Hord, Peyton R.
Lauman, August H., Jr.
Peirce, E. Converse
Rodgers, James Franklin
Stewart, William H.
Watts, Joseph
Witmer, Charles Kendrick

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Gring, Wilbur David
Williams, Howard L.
Livermore, Arthur C.

JUNIOR

Wilson, Edward Firth

Application for transfer was received from Mr. R. E. Polk, who joined the Society June, 1919. After discussion, the Board requested that he be transferred to the grade of Member.

The Secretary presented a letter of resignation from Mr. M. J. Dowling who joined the Society November, 1900. After discussion it was ordered accepted.

The reports of the Secretary showing the financial condition of the Society at close of business April 30, and May 31, 1920, having been regularly audited by the Finance Committee, were approved.

COMMITTEE REPORTS

Mr. James, Chairman of the Entertainment Committee, stated that the committee had arranged and held several different forms of entertainment during the past month as follows:

April 24—Inspection Trip—LaBelle Iron Works.

Attendance	81
Expenses	$396.85
Receipts	244.50

Entertainment—Carnegie Institute of Technology.

Expenses	$ 12.50

May 7—Dinner-Dance.

Attendance	64
Expenses	$198.50
Receipts	96.00

May 15—Informal Dinner—French Naval Officers.

Attendance	35
Expenses	$155.75
Receipts	96.25

June 10—Boat Excursion.

Attendance	147
Expenses	$526.21
Receipts	288.00

The policy has been to make the price of entertainments as low as possible, so that every one might attend. This has caused a deficit in entertainments held, but the Committee felt that the Society should be able to spend some money in this way for the entertainment of its members, and trusts the Board of Direction will consider the matter in this light.

Mr. James stated further he would like an expression from the Board as to whether this was the proper course to pursue. The Committee felt that by giving various entertainments, it would react on the attendance at the technical meetings of the Society.

Several members of the Board stated they felt the Committee was working along the proper lines and that it was very important that the Society endeavor to build up its attendance at both our technical and social functions.

Mr. Minton, chairman of the Finance Committee, stated that the books and financial statements of the Society for the months of April and May were checked and approved.

The expenses were rather heavy for the month of May on account of unusually large bills for publishing and cuts, due to bringing the publications of PROCEEDINGS more nearly up to date, than has been customary in the past. There will be a credit, however, of approximately $200.00 on sale of cuts to authors of several papers.

The item for magazine racks is also included in the May expenditures.

It has been customary during the last two years to have the books audited by Ernst & Ernst and it is recommended that this practice be continued. They have agreed to audit the books at the same rate at which this work was done last year, at an approximate cost of $200.00.

It is also recommended that the certified annual financial statement of the Society be published and mailed to the members.

It was moved and carried that the report of the Committee be accepted as written and the recommendations made therein carried out.

Mr. Schatz, Chairman of the House Committee, reported an evening attendance of 30 for the month of May.

The Committee, accompanied by Mr. Callender, called at the William Penn Hotel to look at the Blue Room which Mr. Shaw, renting agent of the Frick Buildings, wished us to use as an auditorium for the remainder of our lease for our meetings which are held on the first, third and fourth Tuesdays of each month, the Frick Estate to pay for the use of this room. It has a seating capacity of 300 and one end can be arranged for a motion picture screen and all facilities for connecting the lantern.

Mr. Schatz stated that the Committee would like the Board to make recommendations in regard to Mr. Shaw's proposition as soon as possible.

After considerable discussion, it was moved and carried that the House Committee be authorized to accept the proposition submitted by Mr. Shaw, for the use of this room the first, third and fourth Tuesdays of each month, except July and August, provided details as to arrangement can be made satisfactory to the Engineers' Society, with absolutely no additional expense to the Society.

The Secretary presented the following report of the Organization Conference held in Washington June 3 and 4:

Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

In accordance with instructions at the last meeting of the Board of Direction, the writer attended the Organizing Conference held in Washington, D. C., June 3 and 4, as a representative of this Society.

I attended all sessions of the Conference and served on the Committee of Constitution and By-Laws, of which I was made a member.

The Conference was called to order by temporary chairman, Thursday morning, June 3. The first business taken up was the election of a permanent chairman. The Chair then called the Conference to order stating the purpose for which it had been called and suggested that the first matter to be decided was whether or not, in the opinion of those present, an organization such as suggested should be formed. Major Gardner S. Williams, representing the Grand Rapids, Mich. Engineering Society, offered the following resolution, which was seconded, and after discussion adopted:

Resolved, That it is the sense of this Convention that an organization be created to further the public welfare wherever technical knowledge and engineering experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions and further,

That it is the sense of this Convention that the proposed organization should be one of Societies of affiliations and not of individuals.

Before putting this resolution to a vote by roll call, the Chair in answer to a question from the floor stated that as it was understood that practically all the delegates present were uninstructed and would necessarily have to report back to their respective organizations, their vote on any motion put before the Conference would not in any way bind the organization they represented, but would merely be a personal expression of approval or disapproval of any action taken.

Your delegate, therefore, voted in favor of Major Williams' resolution, feeling that the Engineers' Society of Western Pennsylvania should go on record as approving any movement which had for its object a closer cooperation among the engineering societies throughout the country and to further public welfare. He also felt that this should be an organization of Societies rather than individuals.

The resolution brought forth quite a spirited discussion from the American Association of Engineers' representatives, who stated that they felt the A. A. E. was now doing the work for which the new organization was being formed and suggested that all engineers be encouraged to join their organization making one large organization of individuals rather than of Societies. In answer to this suggestion it was pointed out that with the best possible success the A. A. E. could not hope to get more than 50 per cent or 60 per cent of the engineers throughout the country in their Society; while the suggested organization would represent probably 90 per cent of the engineers throughout the country, and as the prime object of this movement was to unite all the engineers for public welfare work, the organization suggested would fill the need far better as one of Societies rather than of individuals.

A total of 119 votes were cast in favor of the resolution, five societies did not vote. Three committees were next appointed: first on Constitution and By-Laws; second on Resolutions, and third on Program. Each of these committees consisted of about 20 members.

The next important matter to be voted on was the Constitution and By-Laws. As stated above your delegate was made a member of the Committee on Constitution and By-Laws, and believes that in general both the Constitution and By-Laws are very fair in their method of representation and finances to both local and national societies. (Copy of Constitution and By-Laws attached hereto.)

It is provided in the Constitution that National Societies shall pay $1.50 a member, and local societies $1.00 per member per year for the support of this organization.

When the Constitution and By-Laws were put to a vote, there were 88 affirmative votes, and 8 societies went on record as being present but not voting. The American Association of Engineers did not vote, their representatives stating that they did not feel the organization could afford to contribute the amount which would be necessary, should they join the organization.

It was further moved and carried that the work of this organization be turned over to Engineering Council with the request that they carry on the work until such time as the new organization began to function. It was stated on the floor of the Conference by a member of Engineering Council that they stood ready to take over the work of the new organization and pledged themselves to carry on the work until such time as the new organization came into existence.

The title given the new organization was The Federated American Engineering Societies.

Your delegate respectfully recommends that the Board of Direction give this matter its consideration, and if thought advisable that a special meeting of the Society be arranged for next Fall at which the matter might be generally discussed and a letter ballot taken thereafter.

There is some question in the writer's mind as to how many of the local organizations throughout the country will join the new organization but he believes that if it is seen that the local societies are taking it up and considering it favorably, the Engineers' Society should, if possible, take out a membership.

The principal question to be settled among the local societies will probably be that of financing, as this seems to be the question uppermost in the minds of the various representatives. It might also be pointed out that in accordance with the Constitution, the Engineers' Society may have a representative on the Council; the local chapters of the various National societies could not be represented, except through an organization such as we are now attempting to form, viz., the Associated Engineering Societies of Pittsburgh.

Respectfully submitted,

K. F. Treschow, *Secretary.*

After discussion, it was moved and carried that the report be accepted and filed.

Mr. Hawley presented the matter of assistant in the Society office, stating that it was felt the Secretary should have an assistant in order that there might be some one who could carry on the work of the Secretary should it be necessary.

After discussion it was suggested that we might be able to secure a young man who would be willing to begin work at one o'clock in the afternoon and work through until 10:30 in the evening, thereby releasing the man it is now necessary to employ to keep the rooms open in the evening.

It was moved and carried that the Secretary be authorized to go into the matter and when ready to take action that the Chairmen of the Finance and House Committees be authorized to employ an assistant in the office.

On motion the meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The Regular Bi-Monthly Meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Tuesday, June 1, at 8:30 P. M., Chairman George T. Ladd presiding, 37 members and visitors being present.

The Minutes of the last meeting held April 6 were read and approved.

No further business coming before the Section, the paper of the evening on "Status of Smoke Abatement," was presented by Mr. Osborn Monnett, Consulting Engineer, Chicago, Ill.

The ensuing discussion was participated in by: John O'Connor, Jr., Secy., Smoke & Dust Abatement League of Pittsburgh, Pittsburgh, Pa.

On motion, duly seconded and approved, a vote of thanks was extended to Mr. Monnett for his very interesting paper.

The meeting adjourned at 9:40 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 387th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade, Tuesday, June 15, at 8:20 P. M., President W. C. Hawley presiding, 48 members and visitors being present.

The Minutes of the last meeting held May 18 were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member, one to the grade of Associate Member, and one to the grade of Junior and the receipt of 12 applications for membership. Four resignations were accepted.

No further business coming before the Society, the paper of the evening on "Factors Which Influence the Selection of Motors For Main Roll Drive," was presented by Mr. G. E. Stoltz, General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

The ensuing discussion was participated in by: W. Trinks, Professor, Mechanical Engineering, Carnegie Institute of Technology; J. R. Buchanan, Local Engr., General Electric Co., Pittsburgh; H. M. Van Deventer, National Tube Co.; W. B. Skinkle, Carnegie Inst. of Technology; Ollie Needham, Gen. Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., and the author.

It was moved, seconded and carried unanimously that a vote of thanks be extended to Mr. Stoltz for his very interesting paper.

On motion the meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms; Union Arcade Building, Thursday, September 9, at 4:30 P. M., Vice President H. D. James, presiding, Messrs. Hunter, Hildner, Stucki, Fohl, Snyder, Schatz and the Secretary being present.

The Minutes of the last regular meeting held June 17, were read and approved.

Applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Gring, Wilbur David — Livermore, Arthur C. — Williams, Howard L.

JUNIOR

Wilson, Edward Firth

The applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Butt, Howard — Hammel, Stanley Samuel

The Secretary reported the death of Mr. J. S. Seaman, Jr., who joined the Society May, 1903, and died September 21, 1919.

The Secretary read a letter from Mr. J. H. Minton, stating that as he had moved his residence to Cleveland, it would be necessary for him to resign as a member of the Board of Direction and Chairman of the Finance Committee.

After discussion, it was moved and carried that Mr. Minton's resignation be accepted, with regret and that the Secretary notify him accordingly.

COMMITTEE REPORTS

In the absence of Mr. Schatz, Chairman of the House Committee, the Secretary made a verbal report stating that negotiations had been completed with the Estate of H. C. Frick for the use of the Blue Room, William Penn Hotel, for all future meetings of the Society during the remainder of our present lease.

The Chairman of the House Committee and Finance Committee in accordance with instructions of the Board, has employed Mr. R. M. Radle, as assistant in the Society office at a salary of $100.00 per month. Mr. Radle has agreed to work from 1:00 to 10:30 P. M., for at least six or seven months, thereby saving the additional expense of a young man to keep the rooms open in the evenings.

There was an evening attendance of 22 for the months of June, July and August.

On account of the summer vacation, no other committee reports were submitted.

The Secretary presented a letter from Mr. W. C. Coryell, Construction Engineer, General Fireproofing Company, of Youngstown, Ohio, in regard to the activities of the Engineers' Society, suggesting certain policies which our Society should adopt.

As it was not clear to the members of the Board just what Mr. Coryell had in mind, the Secretary was requested to write, asking him to elaborate on the suggestions in order that the matter might be taken up at a future meeting.

The Secretary presented a letter from Mr. U. N. Arthur, Chief Engineer, Department of City Planning, which after discussion, was referred to the Civic Affairs Committee for their consideration.

The meeting adjourned at 5:10 P. M.

K. F. TRESCHOW, *Secretary.*

SPECIAL MEETING OF BOARD OF DIRECTION

A special meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Monday, September 20, at 4:00 P. M., President W. C. Hawley presiding, Messrs. Fohl, Stucki, Schatz, Hunter, Snyder, Neilson, Ladd and the Secretary being present.

Mr. Hawley stated that the meeting had been called to consider the report of the Civic Affairs Committee on the matter of the removal of the

present incumbant of the position of County Road Commissioner and the appointment of a candidate to fill the position. Mr. Hawley also stated that this matter had been called to his attention and the suggestion made that the Society take the matter up, as it had been currently reported that the man proposed for this position had had absolutely no technical training and was in no way fitted for the position, whereas the present Road Commissioner had given satisfactory service in every way, the reason for his removal being purely political.

Mr. Fohl then took the floor, stating that the Civic Affairs Committee, together with a committee from the Pittsburgh Section of the American Society of Civil Engineers, had gone in a body to question the County Commissioners in regard to the matter, but was unable to see more than one Commissioner. He stated that in his opinion the position should be filled by a technical man and that to the best of his knowledge, Mr. Warren had given very satisfactory service and should be continued in his present position.

Arrangements were then made for a meeting with the three Commissioners for Tuesday morning, September 21, at which time any resolution which the Board might make would be formally presented.

After discussion, the following resolution was unanimously adopted:

To the County Commissioners,
Allegheny County, Pennsylvania:

Whereas: The attention of the Board of Direction of the Engineers' Society of Western Pennsylvania has been called to the fact that the present incumbent of the position of County Road Commissioner has been asked to resign, and that his successor is about to be appointed; and

Whereas: We have been informed that the present Road Commissioner has given satisfactory administration, and that his removal at this time would be detrimental to the public welfare, on account of the large amount of road work under consideration, amounting to approximately ten million dollars, and the settlement of a large number of contracts with the details of which he alone is familiar; and

Whereas: It is currently reported that the leading candidate for the position does not possess the qualifications necessary for a position of this character, which requires a thorough engineering training and broad construction experience; Therefore,

Be It Resolved: The Board of Direction of the Engineers' Society of Western Pennsylvania at a special meeting held Monday afternoon, September 20, deprecates the proposed action of the County Commissioners in removing a competent official without giving reason for his removal, and urgently requests that if they proceed with the removal of the present Road Commissioner, that his successor be chosen with due regard to his engineering training and experience in road construction.

The meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 388th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, September 21, 1920, at 8:00 P. M., President W. C. Hawley presiding, 60 members and visitors being present.

The Minutes of the last regular monthly meeting held June 15 were read and approved.

The Board of Direction reported the election of two applicants to the grade of Member and one to the grade of Junior, and the receipt of two applications for membership.

The Minutes of the Special Meeting of the Board of Direction held September 20 in regard to the matter of removal of Mr. R. V. Warren, County Road Commissioner, and the appointment of Mr. Roy Schooley, together with resolution adopted by the Board for presentation to the County Commissioners, were read by the Secretary.

Announcement was made of the following appointments to the Nominating Committee, who are to nominate officers for the year 1921.

Samuel A. Taylor, *Chairman,*
Fred C. Schatz,
John N. Chester,
Howard M. Wilson,
Samuel W. Dudley.

Mr. F. N. Speller has been appointed Chairman of the Finance Committee to take the place of Mr. J. H. Minton, resigned.

Mr. W. C. Hawley, President, presented a silver medal, awarded by the Board of Direction, through its Medal Award Committee, for the best paper presented the past year to Mr. A. E. Crockett for his paper on "Cast-Steel Anchor Chain."

Mr. Crockett addressed the Society as follows:

*Mr. President and Fellow Members
and Friends of the Engineers' Society:*

In accepting this medal from the Engineers' Society, I do it with a great deal of pleasure, not for myself, but for those men who so loyally and unselfishly devoted hard hours to the development and manufacture of cast steel anchor chains for vessels. They did not spare themselves, no hours were too long, no problem was too great to undertake to come to the rescue of our Government at a time when it seemed physically impossible with the facilities at hand in our country to produce sufficient chains to meet the needs of the Government; not because the regular manufacturers were not willing to do everything they could do, but there did not seem to be the skilled labor in the United States to weld the links that should hold the vessels to the anchoring, to give them safety in time of storm and to

give them a safe harbor. On behalf of these men and the Companies who told the men to "go to it," and the foundry that turned half of their plant over and simply said, "Gentlemen, it is yours, do with it as you will, and when you are through with it, we will take it back and go on and take our chances in the market and continue to do business at the old stand;" on behalf of these men and their loyalty, unselfishness and patriotism, I accept this as a token from the Society to all who participated in that great act.

No further business coming before the Society, the paper of the evening on "Small Steam Turbines," was presented by Mr. W. J. A. London, President, The Steam Motors Co., Springfield, Mass.

Written discussion was presented by Mr. J. A. MacMurchy, Engr., Small Turbine Engineering Dept., Westinghouse Elec. & Mfg. Co.

The ensuing discussion was participated in by: Grant D. Bradshaw, Pres., Andrews-Bradshaw Co.; G. G. Bell, Gen. Mgr., West Penn Railways Co.; H. A. Rapelye, Manufacturers' Agent; Francis Hodgkinson, Chf. Engr., Machine Works, Westinghouse Elec. & Mfg. Co., and the author.

On motion duly seconded, a unanimous vote of thanks was extended to Mr. London for his very interesting and valuable paper.

On motion the meeting adjourned at 10:20 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, October 7, 1920, at 4:15 P. M., President W. C. Hawley presiding, Messrs. Danforth, Neilson, Schatz, Spellmire, Ladd, Speller, Paul, Snyder, Fohl, and the Secretary being present.

The Minutes of the last regular meeting held September 9 were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Butt, Howard	Hammel, Stanley Samuel

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Eavenson, Howard Nicholas	Freeman, Conrad F.
Davidson, Carl Schaeffer	Skinner, Bradley Lawrence

The Secretary presented letters of resignation from the following gentlemen, which after discussion were ordered accepted:

Izod, Joseph R	Miller, W. P.
Kirk, M. D.	Stephenson, Bertram S.

The Secretary reported the death of the following gentlemen:

O'Donnel, R. L............	Joined Feb., 1917	Died Sept. 28, 1920
Stalknecht, A. C.........	Joined Mar., 1914	Died Oct. 1, 1920

The reports of the Secretary showing the financial condition of the Society at the close of business June 30, July 31 and August 31, 1920, having been regularly audited by the Finance Committee, were approved.

The Secretary reported that Mr. Paul S. Whitman a member of the Finance Committee had gone over the books of the Society for the months of June, July and August and found them to be correct.

In the absence of Mr. James, Chairman of the Entertainment Commitee, the Secretary reported verbally, stating that the Committee had under consideration the matter of securing speakers for the Annual Banquet; also that arrangements have been completed for the Dinner-Dance to be held Friday evening, October 15 at the Hotel Chatham. Arrangements have also been made for an Inspection Trip through the Seamless Tube Plant, National Tube Company, Ellwood City, Pa., to be held Friday, October 22.

Mr. Schatz, Chairman of the House Committee, reported that the Committee still had under consideration the matter of our auditorium, as the William Penn Hotel was not willing to sign the agreement submitted by the Frick Estate. Several meetings were held, at which Mr. Schatz, the Frick representatives and the William Penn Hotel people were present, to discuss the matter of a difference of $5.00 between the price originally agreed upon and the final lease as submitted to the William Penn Hotel. The hotel people brought up the question of using another room in the basement, now being finished, instead of the Blue Room, asking us not to pass final judgment on the matter until the room was completed. A tentative arrangement for meetings from now until the first of December was made and no final lease will be signed until that time.

The Board of Direction authorized the Committee, at a meeting held in the Spring, to have the furniture in the Club Rooms repaired and cleaned. Bids were secured from several firms and contracts awarded to the lowest bidder.

The evening attendance for the month of September was 26.

Mr. Schatz requested the Secretary to report on the work done by the Committee in regard to purchasing new rugs for the Club Room and Library. The Secretary stated that the rugs were in a badly worn condition and as the Committee was having other repairs made, they felt that new rugs should be purchased and the Secretary was requested to obtain prices from firms in the district and report back to the Committee. The price of $799.25 submitted by Jos. Horne Company was $400 to $600 cheaper than could be purchased elsewhere in the city. This was due to the fact that they had the rug in stock and other firms would have had to order it from the factory.

The Committee suggested that as we were endeavoring to increase the membership and as we were having quite a number of visitors in the Club Rooms, they should be kept in first class condition.

After considerable discussion, it was moved and carried that the Committee be authorized to purchase the rugs and the Finance Committee be authorized to take this amount from the Reserve Fund and the money be put back from time to time during the next year, as our surplus would allow.

Mr. Spellmire, Chairman of the Publication Committee, reported that the Committee had held a meeting in the Society Rooms, Tuesday, June 15, at 4:00 P. M.

During the meeting there were a total of twenty-one subjects suggested for papers. After all suggestions had been made the papers were marked "A," "B," "C" or "D" as indicating their desirability and fitness. There were six "A," seven "B" and five "C" and three "D" papers.

There is a total of nine general meetings in the fiscal year of the Society for which papers are required, but it becomes necessary to provide for subjects and authors considerably in excess of the number of papers required, this owing to unforseen conditions which may make it inconvenient for the author to present a paper on a given date. The program of papers gives promise of being carried out as arranged.

The Secretary reported verbally stating that the Membership Committee had held a meeting September 29th, at which ways and means were discussed for increasing the membership and interesting engineers in the district who are not now members, in the work of the Society. It was decided to prepare a list of prominent engineers and executives in the district to be submitted to the Board for their approval, suggesting that invitations be sent to them to join the Society without the formality of filling the usual application blank. This plan was tried several years ago with good results. The Committee recommends that the Board approve the list as recommended. The Secretary read the list submitted and the names were approved with a few exceptions and the Committee authorized to carry out the plan suggested.

Mr. Hawley brought up the matter of the election of a member to fill the vacancy on the Board of Direction caused by the resignation of Mr. Minton. It was moved and carried that as this was a very important matter and the members had probably not given it any consideration, it might be well to hold the matter over until the November meeting.

The matter of finances of the Society was brought up with special regard to increased expenses due to high prices and various means of increasing the revenue were discussed. It was moved and carried that the Finance Committee go into the matter of expenditures and receipts and report back to the Board as to their findings.

It was further moved and carried that the Chairman of the Finance Committee be authorized, if necessary, to draw $500.00 from the Reserve Fund to tide over the finances of the Society to the first of the year.

Mr. Hawley brought up the matter of financing the books of the Society, suggesting that the books be audited from January 1 to December 31, instead of our present plan—from June 30 to July 1. Mr. Hawley

pointed out that all our reports and our fiscal year ended with December, and he felt that our audit should cover the same period. After discussion it was moved and carried that future audits be made as of December 31.

The Secretary read a letter from a special committee of the City Council, which after discussion was referred to the Civic Affairs Committee with the suggestion that they get in touch with Mr. Davison, Chairman of the Special Committee of the Engineers' Society who handled the Westinghouse Memorial and if deemed advisable by him, to send a letter to those interested, asking for their opinion on the matter, the results obtained to be referred back to the Board at its November meeting.

Mr. Hawley brought up the matter of the proposed bond issue of $35,000,000 stating that it had been called to his attention and the request made that the Society take some action in regard to it. After discussion, it was moved and carried that the matter be referred to the Civic Affairs Committee for their action.

The Secretary read a letter from Mr. William F. Hall, a member of the Committee on a National Department of Public Works Association, and Chairman of a Sub-Committee on Finance, in regard to letter received from Mr. C. T. Chenery, Secretary of the Association, requesting that the Engineers' Society do something in a financial way to assist.

Mr. Hall asked that this matter be discussed by the Board, as he did not feel that his committee could solicit funds in the name of the Society without authorization from the Board.

After discussion it was moved and carried that no authorization be given the Committee to secure these funds, as it was not felt that it would meet with success at this time, due to the unsettled conditions prevailing and the coming election.

Mr. Hawley brought up the matter of the Federated American Engineering Societies and after discussion it was moved and carried that this be held up until the November meeting of the Board.

The meeting adjourned at 5:35 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The Regular Bi-Monthly Meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Georgian Room, William Penn Hotel, Tuesday, October 5, at 8:15 P. M. Chairman George T. Ladd presiding, 81 members and visitors being present.

The Minutes of the last meeting held June 1, were read and approved.

No further business coming before the Section, the paper of the evening on "Water Gas" was presented by Mr. A. E. Blake, Sales Engineer, Surface Combustion Co., Pittsburgh, Pa.

The ensuing discussion was participated in by: Grant D. Bradshaw, Pres., Andrews-Bradshaw Co.; J. M. G. Fullman, Works Mgr., National Metal Molding Co., Ambridge, Pa.; J. C. Hobbs, Asst. to Supt. Power Stations, Duquesne Light Co.; Strickland Kneass, Jr., Steam Engr., Youngstown Sheet & Tube Co.; A. McArthur, Sales Engr., The Koppers Co.; J. H. Taussig, Gas Engr., Sales Dept., United Gas Improvement Co., Philadelphia, Pa.; H. M. Van Deventer, National Tube Co.; E. Willis Whited, The Koppers Co.; P. A. Young, Mech. Engr., Philadelphia Co., and the author.

On motion the meeting adjourned at 9:35 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 389th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, October 19th, at 8:10 P. M., Vice President H. D. James presiding, 136 members and visitors being present.

The Minutes of the last regular meeting held September 21, were read and approved.

The Board of Direction reported the election of two applicants to the grade of Member and the receipt of four applications for membership. Also four resignations.

No further business coming before the Society, the paper of the evening on "Stores Engineering" was presented by Mr. M. T. Montgomery, General Superintendent, Stores Department, Pittsburgh Railways Co., Pittsburgh.

The ensuing discussion was participated in by: W. F. Bittner, Asst. P. A., Diamond Alkali Co.; J. B. Connally, Mgr. Purchases Mesta Machine Co.; C. H. Edwards, Storekeeper, Ft. Pitt Malleable Iron Co., McKees Rocks, Pa.; C. E .Gray, Chf. Storekeeper, National Tube Co., Ellwood City, Pa.; C. N. Haggart, Structural Engr., Pittsburgh; C. A. Harris, Asst. Gen. Storekeeper, Pittsburgh Railways Co.; A. E. Lanh, Gen. Storekeeper, Mesta Machine Co., W. Homestead, Pa.; Philip H. Lantz, Financial Asst. to President, Philadelphia Co.; D. F. Manice, Eff. Engr., A. M. Byers Co.; C. A. Moekle, Cost Accountant, Dravo Contracting Co.; E. W. Pittman, Gen. Mgr., Dravo Contracting Co.; H. M. Schmitt, Expediter, American Sheet & Tin Plate Co.; W. G. Scott, P. A., R. D. Nuttall Co., and the author.

On motion, duly seconded, a unanimous vote of thanks was extended to Mr. Montgomery for his very excellent paper.

The meeting adjourned at 10:00 P. M.

K. F. TRESCHOW, *Secretary.*

METALLURGICAL AND MINING SECTION

The Regular Bi-Monthly Meeting of the Metallurgical and Mining Section of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, October 26, at 8:25 P. M., Chairman J. W. Paul presiding, 54 members and vistors being present.

The Minutes of the last meeting held March 30th were read and approved.

There being no further business coming before the Section, the paper of the evening on "Sulphur in Coal and Coke," was presented by Dr. Alfred R. Powell, Physical Organic Chemist, U. S. Bureau of Mines, Pittsburgh, Pa.

Written discussion was received from: F. F. Marquard, Supt., By-Product Coke Works, Carnegie Steel Co., Clairton, Pa.; J. R. Campbell, Chf. Chemist, H. C. Frick Coke Co., Everson, Pa.; F. W. Wagner, Asst. Chf. Chemist, Jones & Laughlin Steel Co.; R. W. Campbell, Chief Chemist, Jones & Laughlin Steel Co.

The ensuing discussion was participated in by: W. F. Ellwood, Chemical Engr., Keystone Coal & Coke Co., Greensburg, Pa.; A. C. Fieldner, Supt., U. S. Bureau of Mines; F. W. Sperr, Chief Chemist, The Koppers Co., and the author.

It was moved and seconded and carried unanimously that a vote of thanks be extended to Dr. Powell for his very interesting paper.

On motion the meeting adjourned at 10:20 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The Regular Monthly Meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building, Thursday, November 4th, at 4:15 P. M., President W. C. Hawley presiding, Messrs. James, Danforth, Hunter, Speller, Schatz, Paul, Snyder, Neilson and the Secretary being present.

The Minutes of the last regular meeting held October 7th were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Davidson, Carl Schaeffer
Eavenson, Howard Nicholas
Skinner, Bradley L.
Freeman, Conrad F.

Applications from the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Crew, Joshua Arthur
Fitzgerald, Thomas
Knopf, J. R.
Selkirk, W. Marshall (Member A.S.M.E.)
Smith, Howard Wells (Member A.S.M.E.)
Sollie Klaus
Tracy, Louis Donner

ASSOCIATE MEMBERS

Adams, Howard Clark
Hesselink, Lawrence Rynhart
Kerr, William Given
Lacy, Robert (Member A.S.M.E.)
Van Deventer, Frank M.

Requests for reinstatement were received from Mr. Robert O. Rall and Mr. Homer J. Keebler, and the Board requested that letters be written to these gentlemen, advising that their names had been placed on the Society Rolls.

The Secretary presented letters of resignation from the following gentlemen which after discussion were ordered accepted:

Brennan, W. A................................Joined June, 1911
Davis, H. P.....................................Joined Dec., 1898
Rogers, F. D...................................Joined Feb., 1918

The Secretary reported the death of Mr. Patrick Noble who joined the Society February, 1882, and died October 2nd, 1920.

The Secretary presented the name of Mr. J. A. Spielmann, who had called at the office in regard to dues owing for the years of 1918-19-20. Mr. Spielmann stated that he understood, according to the By-Laws, that he had been dropped from membership and under these conditions would not pay dues. After discussion it was moved and carried that his name be dropped from the rolls of the Society.

The report of the Secretary showing the financial condition of the Society at the close of business September 30th, having been regularly audited by the Finance Committee was approved.

Mr. Hawley called attention to the vacancy on the Board of Direction caused by the resignation of Mr. J. H. Minton, stating that this matter had been held over from the last meeting. After discussion, it was moved and carried that this matter be held over until the next meeting of the Board.

Mr. James, Chairman of the Entertainment Committee, reported as follows:

Entertainment Committee held two social events and one inspection trip during October and September. The Boat Excursion held September 14th had an attendance of 142. Receipts $87.50, expenses $244.25, showing a deficit of $156.75. It was fairly well attended and every one seemed to have a good time.

The Dinner-Dance held October 15th had an attendance of 36 only. The expenses were in excess of receipts to the amount of $119.25.

Inspection trip held October 22nd had an attendance of 80 members. Two special trolley cars were provided to take the members to Ellwood City. Expenses of trip to the Society $48.90.

Annual Dinner. Preliminary selection of January 24th as date of dinner. We have promise of speaker of national reputation, and believe dinner will prove equal to high standard maintained by the Society.

Mr. Speller, Chairman of the Finance Committee, reported as follows:

The correctness of monthly statement dated September 30th was verified in usual manner.

In accordance with instructions from Board of Direction, Committee went into cause of general increase in expenditures over receipts. Auditor's report of June, 1920, shows that 80 per cent. was due to increased cost of printing, which shows an increase of 100 per cent. over previous year.

There was no corresponding increase in advertising rates, but volume of advertising was increased about 40 per cent. during this period.

Committee has not gone into problem as to what can be done to bring about a better condition in financial affairs, but will endeavor to look into the matter in more detail and report at December meeting of the Board.

In the absence of Mr. Schatz, Chairman of the House Committee, the Secretary reported as follows:

The House Committee desires to report an evening attendance of 87 for the month of October.

The program for the improvement of the Club Rooms and Library has been completed in accordance with previous report of Committee.

The Committee still has under consideration the matter of auditorium, several meetings having been held during past month with the Frick people and officers of the Wm. Penn Hotel. The lease covering the use of the Palm Room was submitted and after consultation with Mr. Hawley, was returned unsigned. A new lease was substituted within the last few days, which gives us the refusal of a new room called the Lounge Room, which is being finished in the basement and which will, from the standpoint of capacity be better suited to our needs in that it contains no columns.

Mr. Spellmire, Chairman of the Publication Committee, reported as follows:

The Publication Committee has no report to make other than that the program of papers as laid out tentatively gives promise of being carried out satisfactorily.

The Nominating Committee presented the following report:

Pittsburgh, Pa., November 3, 1920.

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

At a meeting of the Nominating Committee of the Engineers' Society of Western Pennsylvania, held in the Society Rooms, Wednesday, November 3rd, the following gentlemen were chosen unanimously for the respective offices indicated below:

For President..............................George H. Danforth
For Vice President..........................Morris Knowles
For Treasurer..A. Stucki
For Directors.............................. { L. F. W. Hildner, George T. Ladd }

Respectfully submitted,

NOMINATING COMMITTEE,

SAMUEL A. TAYLOR, *Chairman;*
J. N. CHESTER,
H. M. WILSON,
FRED C. SCHATZ,
S. W. DUDLEY.

Mr. Hawley brought up the matter of a new lease submitted by the Frick Estate as mentioned in Mr. Schatz's report, stating that in view of the fact that the Frick Estate had not carried out their original plan and given us the Blue Room, also as the rooms which they had given us up to the present time were not in accordance with our lease or suited to our needs in that each room had four columns, which cut down the seating capacity to about 175, he did not feel that he could take the responsibility of signing the lease until after the Board had gone into the matter.

Mr. Hawley stated that he had written the Secretary a letter giving his ideas on this matter and asked him to read it in order that the Board might become acquainted with all the facts in the case. Mr. Hawley pointed out in the letter that the Society had agreed to the change in order to accommodate the Frick Estate during the period of the war, but that they should now provide us with quarters as provided in our lease.

Mr. Hawley stated that he would like the Board members to go over to the hotel and inspect the two rooms suggested so that they may make recommendations as to whether or not we should agree to the use of these rooms.

In view of the lateness of the hour and to the fact that the Committee was waiting to appear before the Board, it was moved and carried that this matter be taken up at an adjourned meeting of the Board to be held next Thursday, November 11th.

A special Committee from a new organization being formed known as the Practicing Engineers, composed of Mr. L. P. Blum, chairman, and F. G. Ross and A. E. Duckham, presented themselves before the Board stating that they had been requested by their organization to take up with the Engineers' Society the matter of affiliation for becoming a Section of our Society. Mr. Blum asked Mr. Ross to take the floor. He stated that arrangements could possibly be made whereby the Practicing Engineers Organization could come in as a Section of the Engineers' Society of Western Pennsylvania.

The main points under discussion were:

1. Finances.
2. Eligibility of the men now belonging to the Practicing Engineers.
3. The question as to eligibility of voting at these meetings.

In regard to this question Mr. Ross stated that under the present Constitution of their organization only one member from each firm was permitted to vote. This would have to be made to conform with the By-Laws of the Engineers' Society.

After a general discussion it was moved and carried that the President appoint a special committee from the members of the Board of Direction

to confer with this committee and report back to the Board at the adjourned meeting of the Board to be held Thursday, November 11th.

Mr. Hawley thereupon appointed Mr. John A. Hunter, chairman; Mr. James and Mr. Danforth as members of this committee.

It was moved and carried that the meeting be adjourned until Thursday afternoon, November 11th, at 4 P. M.

K. F. Treschow, *Secretary.*

SPECIAL MEETING

The adjourned meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Union Arcade Building Thursday, November 11th, at 4:25 P. M., President W. C. Hawley presiding, Messrs. Danforth, Stucki, James, Fohl, Ladd, Snyder and the Secretary being present.

Mr. Hawley stated that this was a continuation of the meeting held last Thursday as it had been found, due to the lateness of the hour there were several matters which could not be taken up at that time, the first being the question as to what action our Society should take in regard to the Federated American Engineering Societies.

The Secretary read a letter from Mr. Charles F. Scott, a past president of the Society urging that the Society consider favorably the joining of this organization.

After a general discussion as to the advantages of the organization, financial responsibility, etc., it was moved and carried that a special meeting of the Society be called for either December 1st or 8th, and that some member of the Joint Conference be invited to address the meeting and reply to any questions that might be asked, and further that after this meeting a referendum vote be taken as to whether the Society should join this organization, as well as the manner in which the financial part of it should be taken care of.

In the absence of Mr. Hunter, chairman of the Special Committee, appointed by Mr. Hawley at the last meeting of the Board of Direction, Mr. Danforth presented a verbal report, stating that after going into the matter thoroughly with a committee from the Practicing Engineers, the Committee recommends that the Board of Direction admit the members of the organization known as the "Practicing Engineers" in a body without the payment of an entrance fee and that the Section of this Society be formed to be known as the Practicing Engineers Section of the Engineers' Society of Western Pennsylvania. It is to be understood, however, that any engineer now a member of the Practicing Engineers, who does not come in at this time, must pay the regular entrance fee when joining the Section.

Mr. Hawley next presented the matter of the revised regulations of the proposed Associated Engineering Societies of Pittsburgh and after discussion it was moved and carried that as they included the amendments suggested by the Board of Direction at the time this was taken up before, they be approved as presented.

The matter of the proposed auditorium in the William Penn Hotel was then taken up by Mr. Hawley, who stated that he would like the Board to personally see these rooms before the lease was signed. The Board then adjourned to the William Penn Hotel to inspect the rooms, after which it was moved and carried that the present lease be signed by the President and Secretary and returned to the Frick Estate.

The meeting adjourned at 5:40 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION

The Regular Bi-Monthly Meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, November 2nd, 1920, at 8:15 P. M., chairman L. F. W. Hildner presiding, 56 members and visitors being present.

The Minutes of the last meeting held May 4th were read and approved.

There being no further business before the Section, the paper of the meeting on "Structural Engineering Problems in Electric Transmission Line Construction," was presented by Mr. James S. Martin, Structural Engineer, Duquesne Light Company, Pittsburgh, Pa.

The ensuing discussion was participated in by: Osmund M. Jorstod, Gen. Engr., Westinghouse Elec. & Mfg. Co.; N. A. Wahlberg, Elec. Engr., Westinghouse Elec. & Mfg. Co.; George S. Humphrey, Elec. Engr., West Penn Power Co.; W. M. Austin, Supply Engr., Westinghouse Elec. & Mfg. Co.; S. S. Hertz, Consulting Electrical Engineer, Pittsburgh; C. W. Kenney, Chf. Civil and Const. Engr., West Penn Power Co.; H. W. Smith, Gen. Engr., Westinghouse Elec. & Mfg. Co.; L. F. W. Hildner, V. P. and Chf. Engr., Pittsburgh Bridge & Iron Works, and the author.

On motion the meeting adjourned at 10:35 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The 390th Regular Monthly Meeting of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, November 16th, at 8:20 P. M., President W. C. Hawley presiding, 77 members and visitors being present.

The Minutes of the last regular meeting held October 19th, were read and approved.

The Board of Direction reported the election of four applicants to the grade of Member and the receipt of twelve applications for membership; two requests for reinstatement and the receipt of three resignations.

There being no further business before the Society, the paper of the evening on "Regional Planning in the Pittsburgh District," was presented by Mr. Morris Knowles, President and Chief Engineer, Morris Knowles, Inc., Chairman, Community Planning Committee, Civic Club of Allegheny County and Director National Institute of City Planning, Pittsburgh.

The ensuing discussion was participated in by: Winter Haydock, Chf. Engr., Citizens' Committee on City Plan of Pittsburgh; E. C. Stone, Asst. to Gen. Mgr., Duquesne Light Co.; Lee Digley, 1440 Penn Ave., Pittsburgh; J. W. Freeman, Sales Engr., Mathews Gravity Carrier Co.; W. C. Hawley, Chf. Engr. and Gen. Supt., Pennsylvania Water Co., and the author.

On motion the meeting was adjourned at 10 P. M.

K. F. TRESCHOW, *Secretary*.

METALLURGICAL AND MINING SECTION

The Regular Bi-Monthly Meeting of the Metallurgical and Mining Section of the Engineers' Society of Western Pennsylvania was held in the Palm Room, William Penn Hotel, Tuesday, November 30th, at 8:15 P. M., Chairman J. W. Paul presiding, 48 members and visitors being present.

The Minutes of the last meeting held October 26th were read and approved.

There being no further business coming before the Section, the paper of the evening on "Mineral Resources of Pennsylvania," was presented by Dr. George W. Ashley, State Geologist, Harrisburg, Pa.

The ensuing discussion was participated in by: J. B. Mandeville, Chf. Engr., T. W. Phillips Gas & Oil Co., Butler, Pa.; Wm. E. Schmertz, Asst. Mgr., Bureau of Instruction, Jones & Laughlin Steel Co., and the author.

It was moved, seconded and carried unanimously that a vote of thanks be extended to Dr. Ashley for his very interesting paper.

On motion the meeting adjourned at 9:45 P. M.

K. F. TRESCHOW, *Secretary*.

Vol. 36 FEBRUARY 1920 No. 1

PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

CONTENTS

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PROCEEDINGS OF THE

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INCORPORATED 1880

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Published Monthly except August and September
E. H. McClelland, Technical Editor

No paper read before the Society shall be published elsewhere before its appearance in the PROCEEDINGS, and no paper previously published shall be published in the PROCEEDINGS without authority from the Publication Committee.

All papers, upon their acceptance by the Publication Committee, become the property of the Society, and it lies within the discretion of the Committee to publish them in whole or in part. The Society, however, does not hold itself responsible for opinions expressed by its members.

The Society will mail to correspondents and advertisers—monthly, except August and September—the PROCEEDINGS; containing the minutes of, and the papers read at, the regular meeting, and at the meetings of the Mechanical; Metallurgical and Mining; and Structural Sections.

An author is entitled to 25 copies of the PROCEEDINGS containing his paper. He may also have any additional number of copies at twenty cents each, provided they are ordered in advance of publication.

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The Secretary will quote prices for volumes 1, and 5 to 16; and for single numbers which are becoming scarce. Volumes 2 to 4 cannot be furnished.

Rate of subscription, throughout the Postal Union, $5 a year; to colleges and libraries, which agree to bind and catalogue, $2 a year.

By sending their unbound PROCEEDINGS to the Secretary, members may have volumes bound at the rate of $1 each.

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

Incorporated 1880

OFFICERS FOR 1920

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W. C. HAWLEY

VICE PRESIDENTS

GEORGE H. DANFORTH HENRY D. JAMES

SECRETARY

KENNETH F. TRESCHOW

TREASURER

A. STUCKI

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Concrete Institute. Transactions
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Technologist
Technology Review
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For Classified List of Advertisers see page xiv

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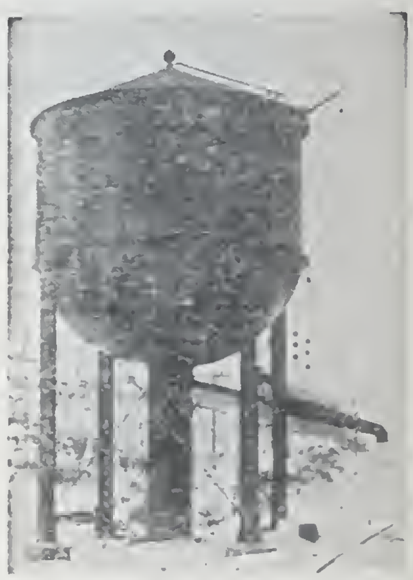

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Continued on page xvii

Continued on page xix

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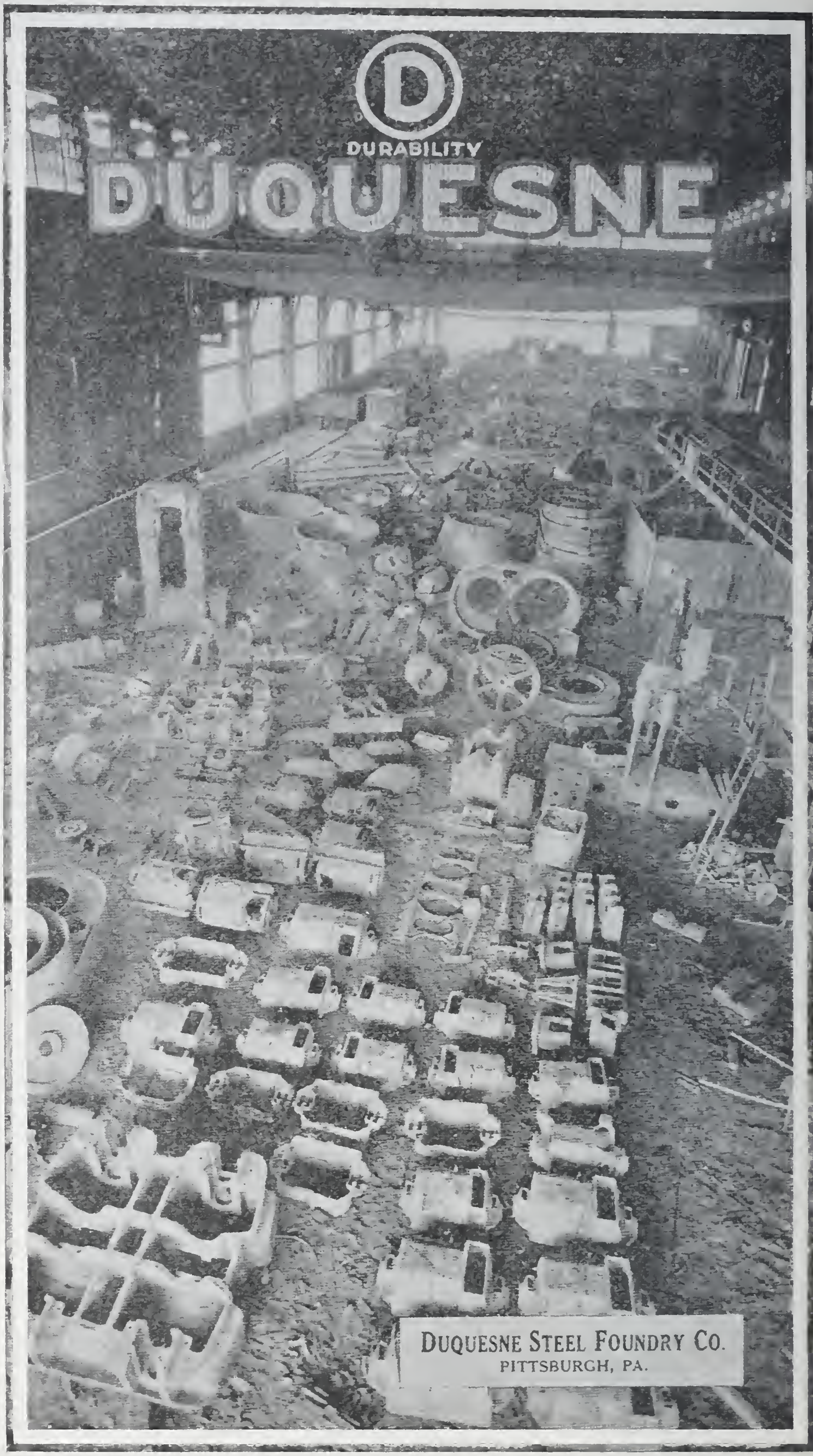
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